NASA CR 72-0-85
AEROJET 3137

SNAP-8 ELECTRICAL GENERATING SYSTEM DEVELOPMENT PROGRAM

PROGRESS REPORT FOR JULY - DECEMBER 1965

prepared for

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION
LEWIS RESEARCH CENTER

CONTRACT NAS 5-417

GPO PRICE $ ______

CFSTI PRICE(S) $ ______

Hard copy (HC) 3.75

Microfiche (MF) 1.25

ff 653 July 65

FACILITY FORM 602

N66 39971 (ACCESSION NUMBER) ______ (THRU)

241 (PAGES) 1 (CODE)

CR-72085 (NASA CR OR TMX OR AD NUMBER) 03 (CATEGORY)

20

VON KARMAN CENTER
AEROJET-GENERAL CORPORATION
AZUSA, CALIFORNIA

Requests for copies of this report should be referred to:

NASA Scientific and Technical Information Facility
P.O. Box 33
College Park, Maryland, 20740

NASA CR 72-0-85
Aerojet 3137

PROGRESS REPORT FOR JULY-DECEMBER 1965

SNAP-8 ELECTRICAL GENERATING SYSTEM DEVELOPMENT PROGRAM

prepared for

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

March 1966

CONTRACT NAS 5-417

Technical Management
NASA Lewis Research Center
Cleveland, Ohio
SNAP-8 Project Office
H. O. Slone, Manager

Von Karman Center
AEROJET-GENERAL CORPORATION
Azusa, California

Report No. 3137

ABSTRACT*

SNAP-8 is a turboelectric, nuclear, space power conversion system using a mercury Rankine cycle. The system incorporates three liquid metal loops. Sodium-potassium (NaK) in the primary loop is heated in a reactor, and in turn heats mercury in a heat exchanger. The mercury vapor, in the second loop, expands through a turbine; it is then condensed and pumped back through the boiler. A third loop, also containing NaK, transfers the heat from the mercury to a radiator where it is rejected to space. The fourth loop contains a polyphenyl ether that lubricates the bearings of the main rotating components and provides necessary cooling for the alternator, electric motors, and controls.

This report covers the progress in development of the SNAP-8 power conversion system and system components during the last half of 1965.

*NASA STAR Category - 03

Report No. 3137

CONTRACT FULFILLMENT STATEMENT

This semiannual progress report is submitted to the National Aeronautics and Space Administration in partial fulfillment of Contract No. NAS 5-417. The report covers the period from 1 July through 31 December 1965.

APPROVED:

Robert Gordon

Robert Gordon, Manager
SNAP-8 Division
Aerojet-General Corporation

CONTENTS

CONTENTS (cont.)

CONTENTS (cont.)

CONTENTS (cont.)

CONTENTS (cont.)

CONTENTS (cont.)

CONTENTS (cont.)

CONTENTS (cont.)

CONTENTS (cont.)

GLOSSARY

Abbreviations commonly used in the SNAP-8 Program are defined below.

AA	Alternator assembly
AEC	Atomic Energy Commission
AGC	Aerojet-General Corporation
AGN	Aerojet-General Nucleonics
AI	Atomics International
AZFO	NASA-Azusa Field Office
CL	Corrosion loop (AGN)
CPP	Continuation Program Plan
DDAS	Digital data acquisition system
DWG	Drawing
EGS	Electrical generating system
EM	Electromagnetic
FCC	Face-centered cubic
FPS	Flight-prototype system
FPTF	Flight-prototype test facility
GE	General Electric Company
GPS	Ground-prototype system
GPTF	Ground-prototype test facility
HCP	Hexagonal close packed
HRF	Heat-rejection fluid
HRL	Heat-rejection loop
HRS	Heat-rejection system
HTL	Heat-transfer loop
L/C	Lubricant-coolant
LCA	Low-temperature controls assembly
LeRC	Lewis Research Center
LML	Liquid-mercury loop
LNL	Liquid-NaK loop
MECA	Mercury Evaporating and Condensing Analysis
M-G	Motor-generator (set)
MIS	Mercury-injection system
Mix-4P3E	Bis(mix-phenoxyphenyl) ether, a mixture of the six possible isomers of bis(phenoxyphenyl) ether, considered as a lubricant-coolant for the PCS
ML	Pyre-ML, Du Pont polyimide organic resin
MPMA	Mercury pump-motor assembly
NaK	Eutectic mixture of sodium and potassium
NASA	National Aeronautics and Space Administration
NHRA	NaK heat-rejection assembly
NPA	NaK pump assembly
NPMA	NaK pump-motor assembly
NPS	Nuclear power system
NPSH	Net positive suction head
NS	Nuclear system
NSL	NaK-simulation loop
ORNL	Oak Ridge National Laboratory
P&I	Plumbing and instrumentation
PCS	Power Conversion System
PCS-1 Phase IV	First complete breadboard nonnuclear system
PF	Power factor
PL	Primary loop
PLR	Parasitic load resistor
PMA	Pump-motor assembly
P/N	Part number
PNL	Primary NaK loop assembly
RPL	Rated-power loop

GLOSSARY (cont.)

SC	Speed control
S8DS	SNAP-8 development system
S8ER	SNAP-8 experimental reactor
SL-1	System Loop Test Facility 1
S/N	Serial number
SNAP	Systems for Nuclear Auxiliary Power
SR	Saturable reactor
SS	Stainless steel
TA	Turbine assembly
TAA	Turbine-alternator assembly
TCL	Thermal-convection loop (AGN)
TRA	Transformer-reactor assembly
TRW	Thompson Ramo Wooldridge
TSE	Test-support equipment
T-T	Tube-in-tube
VKC	Von Karman Center
VR-E	Voltage regulator-exciter
WOO	Western Operations Office
-X, -1, -2, -3	Standing alone (i.e., not preceded by letters of the alphabet), these designations indicate design stages of SNAP-8 hardware

I. INTRODUCTION

The SNAP-8 electrical generating system is being developed by the National Aeronautics and Space Administration for use in various space applications. The system provides 35 kw of electrical power by converting heat from a nuclear reactor into electrical energy. Aerojet-General Corporation is developing the SNAP-8 power conversion system at its Von Karman Center in Azusa, California, under NASA Contract NAS 5-417. The effective starting data of the contract was 9 May 1960. The nuclear reactor is being built for the Atomic Energy Commission by Atomics International, Inc.

This report is the second in a series of Semiannual Progress Reports and includes a discussion and evaluation of the technical progress during the last half of 1965. This series of reports replaces the series of Quarterly Progress Reports published under the contract from its inception through 1964.

II. RATED POWER LOOP 2 (PCS-1 PHASE IV STEP 1)*

A. DESIGN AND ENGINEERING

The PCS-1 Phase IV Step 1 design effort was concentrated on the tube-in-tube boiler installation and buildup of various test support systems.

The vapor line between the boiler and the turbine simulator and the liquid lines between the condenser and the mercury pump-motor assembly (HgPMA) were redesigned. The TSE work included the design and installation of a mercury inventory control system capable of injecting controlled amounts of mercury and/or rubidium. An emergency dump system was also installed to aid in the safe emergency shutdown of the mercury loop.

The space seal vacuum system for the HgPMA was redesigned to increase its capacity and to enable better measurements of gross seal leakage. The lubricant-coolant loop was revised for better system operation and its degassing capabilities improved by installing a higher-capacity vacuum system.

The parasitic load resistor (PLR) was installed in the primary NaK loop (PNL) to preclude major redesign of the PNL piping for Step 2 testing. All instrumentation and electrical systems were recalibrated and upgraded for improved service.

A system review was held on 8 September 1965 (Ref. 1).

B. RESULTS AND ANALYSIS

1. Test Objectives

The basic objective of Step 1 testing was to obtain performance data for the tube-in-tube (T-T) boiler and the -1 condenser. The details of the test objectives are found in the individual test specifications (Refs. 2 and 3). Additional test objectives were added during the test program to obtain boiler startup data. These data were intended for use in the analog simulation of the boiler during a PCS startup.

---

*Because Rated Power Loop 2 is being upgraded from a component test loop to a system test loop, it has been renamed PCS-1 Phase IV. "Step 1" designates the last use of RPL-2 as a component test loop. Steps 2 and 3, system testing, are discussed in Section IV of this report.

The first boiler startup objective was to obtain boiler pressure drop data for numerous combinations of mercury flow rate and boiler outlet pressure. The second objective was met by performing two simulated startups using the -1 mercury flow control valve. The startups differed by the manner in which the NaK-side conditions of the boiler were varied.

2. Test Results

Testing began at 10:56 pm on 30 November 1965 and was completed at 1:15 pm on 12 December 1965. Boiler and condenser performance mapping was started on 9 December 1965.

Step 1 testing (reported in Ref. 4) was very successful. Both the boiler and the condenser performance mapping was completed. The only limitation in the program was the inability to achieve a few of the datum points because of limited NaK-side flow capabilities.

The boiler testing indicated that good boiler performance can be expected during startup. Although the test was a simulation of an actual PCS-1 startup, it was, nevertheless, sufficiently rigid to demonstrate that the boiler starts satisfactorily (i.e., the boiler pressure drop does not become excessive and restrict the flow in the mercury loop).

The performance of the overall system is illustrated graphically in Figures II-1 through II-12. These figures show the plotted data over the entire test period of Step 1. The data are grouped according to appropriate component and loop.

Plots of the key system parameters during the boiler startup simulations are shown in Section VI, Figures VI-45 through VI-48. Figures VI-45 and VI-46 show the startup conducted on 10 December 1965 and Figures VI-47 and VI-48 show the startup conducted on 12 December 1965. These two startups differ by the procedure in which the NaK flow rate was increased. In the former test, the NaK flow rate was raised from one-half to rated flow while the mercury flow rate was held constant at 4400 lb/hr. In the latter test, a more stringent and realistic simulation was made in which the NaK flow rate was increased simultaneously with an increasing mercury flow rate.

In both startups, the system response was satisfactory and a successful startup of the boiler occurred. The plots of the first startup show an excessive rise of the condenser NaK-side temperatures and hence the mercury condensing pressure. This temperature rise was not the result of the inability of the heat-rejection loop (HRL) cooler to follow the startup transient requirements, but because the cooler louvers were inoperative. The problem was corrected and did not occur on the second startup simulation.

The boiler and condenser testing is reported in detail in Refs. 5 and 6.

3. Problems Encountered and Resolved

When mercury was injected on 30 November 1965, an apparently satisfactory startup resulted. The boiler was producing superheat at a mercury flow rate of about 1500 lb/hr. Further opening of the mercury throttle valve, however, gave no increase in flow rate. Analysis of the data indicated strongly that a restriction was occurring at the boiler inlet.

The boiler was X-rayed in place but no sign of a restriction was found. Examination of drawings and plug photographs indicated that no manufacturing error had been made. The boiler inlet line was then cut and the boiler inlet manifold was visually inspected. Also, argon gas was blown through the line between the HgPMA and the boiler.

Neither of these actions revealed any problem. Therefore, it was considered likely that boiling in the tight-pitch (6.5 fps) section of the high-velocity plugs, characteristic of this particular boiler, was the cause of the high pressure drop. An analysis of the problem strongly supported this hypothesis.

Consequently, testing was resumed on 2 December 1965 to confirm the repeatability of the high pressure drop and then to deliberately flood the tight-pitch section of the plug inserts. Flooding would eliminate any plug boiling and thus would indicate whether or not plug boiling caused the high pressure drop.

The repeatability of the high pressure drop was confirmed. The flooding of the tight-pitch section, however, was found to be impossible without flooding the entire boiler. That is, the negligible pressure drop between the plug and the boiler exit permitted the boiler to fill easily with mercury once the interface was moved out of the plug section. It was therefore impossible to hold a steady-state condition in which the pressure drop, exclusive of the tight-pitch section, could be evaluated. However, sufficient data were obtained to demonstrate conclusively that boiling in the plug section, with an associated high pressure drop, always occurred for any conditions other than entire boiler flooding. Hence, it was concluded that the plugs were responsible for the excessive pressure drop.

The boiler plugs were changed (6.5 fps to 4.5 fps), and testing was resumed on 6 December 1965. The boiler pressure drop was normal. However, initiation of boiler and condenser tests was not yet possible for the following reasons:

a. Noncondensibles had collected in the condenser; the noncondensible pressure was about 15-20 psi.

b. The boiler did not condition. At a mercury flow rate of 6000 lb/hr, Hg vapor saturation was indicated at all stations between the boiler and condenser. The indicated Hg vapor quality at the sonic nozzle inlet was about 75%.

c. The vapor-line throttle valve (HGV-15) pressure drop was excessive (about 100 psi at 6000 lb/hr). During the boiler conditioning run (D-3-Z-15), this same valve had a much lower pressure drop (about 10 psi at 6000 lb/hr). The high pressure drop was caused by an erroneous setting of the valve travel mechanism which prevented it from achieving a true full-open position.

d. Loss of mercury inventory caused a shutdown. Investigation indicated that the mercury was slowly leaking into the dump tanks.

Because of these conditions, the loop was shut down and repairs were initiated before boiler and condenser testing was again attempted.

A rubidium injection system was also added because the boiler had not conditioned properly.

On 7 December 1965, the facility was again ready for testing. July as mercury was to be injected, smoke was noted coming from the NaK line leading to the No. 1 gas heater and the loop was shut down. Rather than from a suspected NaK lead, the smoke came from smoldering canvas wrapping on the insulation under the metal wrap where there was an opening in the metal wrap. The opening was sealed with additional metal wrapping, and there was no further problem.

Mercury was again injected on 8 December 1965. A 24-hour boiler conditioning period followed during which sufficient conditioning occurred to eliminate any requirement for rubidium addition.

No further component or facility problems occurred. The condenser tests commenced 9 December 1965 and were followed by the boiler test and the special startup tests. The results of these tests are discussed more fully in Section VI,C of this report.

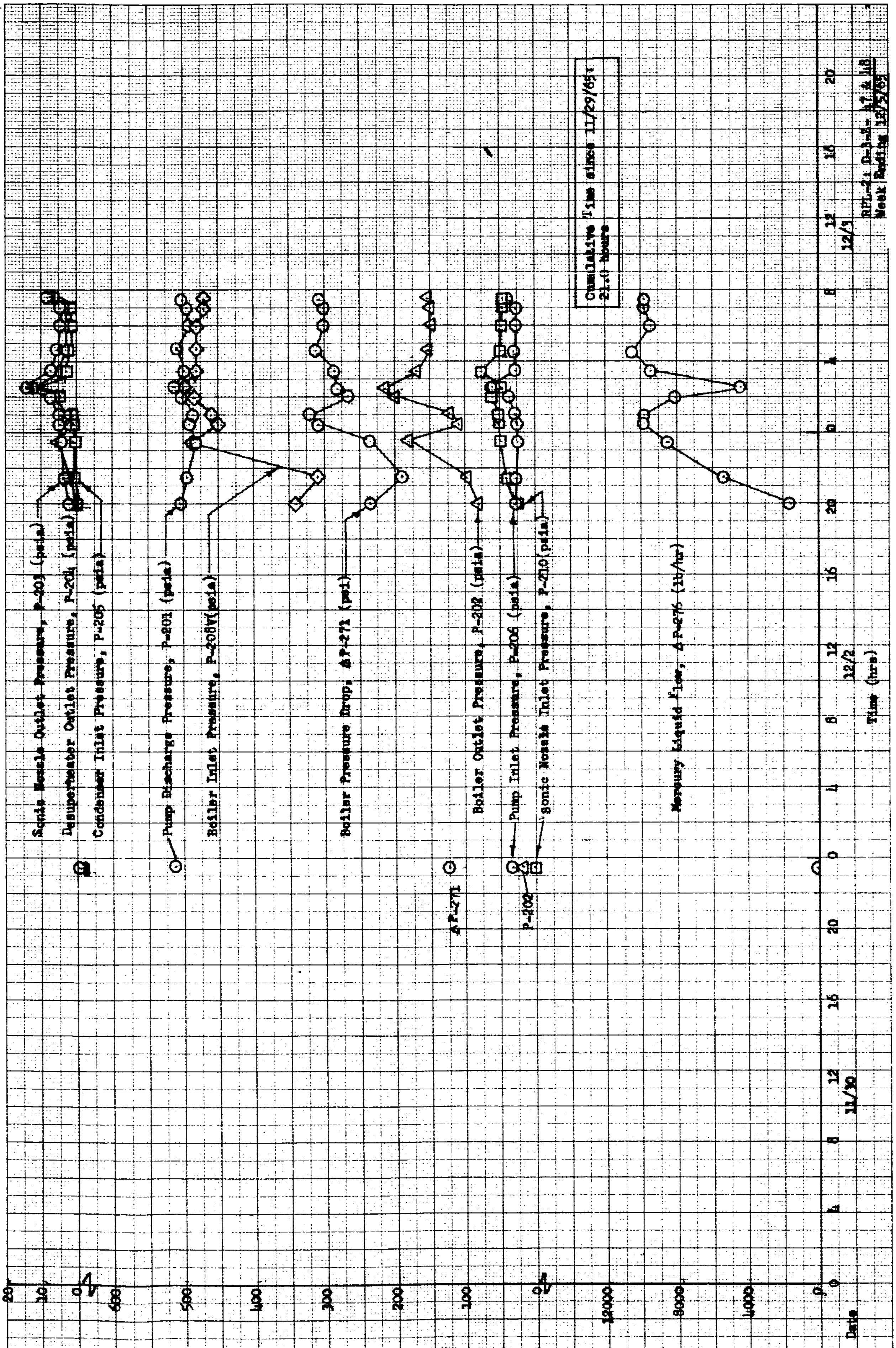
4. Instrumentation Adequacy

The instrumentation for Step 1 testing was generally good. Because of the redundant readings available, it was possible to adequately evaluate component and system performance.

The one basic problem was measuring the liquid mercury flow rate. On each of the two venturi flowmeters used to record flow rate, there were two or more pressure-differential reading instruments. The readings on a given venturi were consistent, but the two sets of readings disagreed by approximately 9%.

An overall analysis of the instrumentation was made to determine the number of apparent instrumentation malfunctions, or questionable readings. Each item of instrumentation was analyzed with respect to redundant readings. Also, each instrument reading was analyzed with respect to its system orientation; that is, each reading was compared to values required by adjoining or related system readings.

It was concluded that the overall instrumentation performance was satisfactory.



Hg Loop Pressures - Run D-3-Z-47 and 48

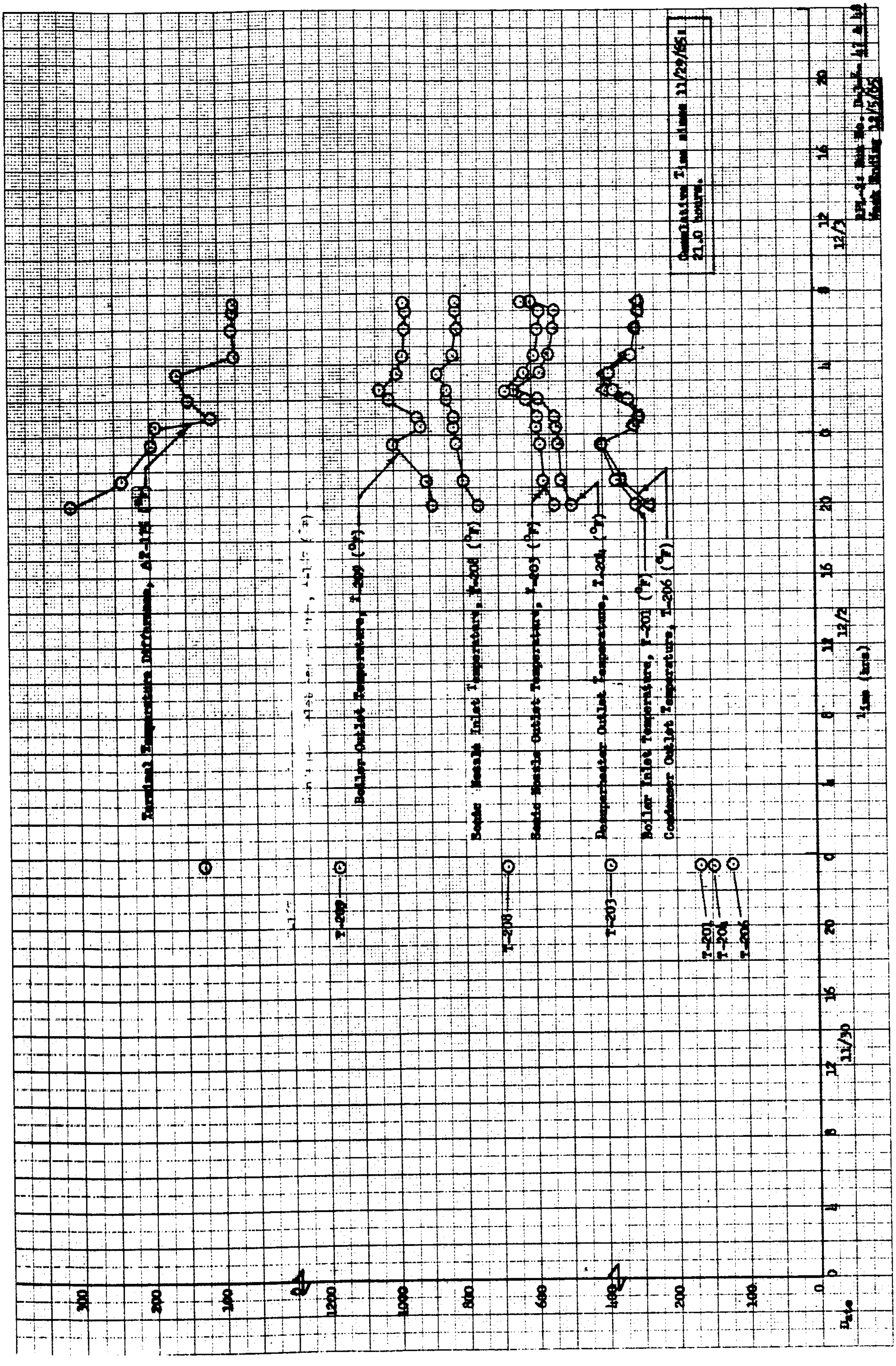
B166-NF-1136

Figure II-1

B166-NF-1137

Hg Loop Pressures - Run D-3-Z-49 and 50

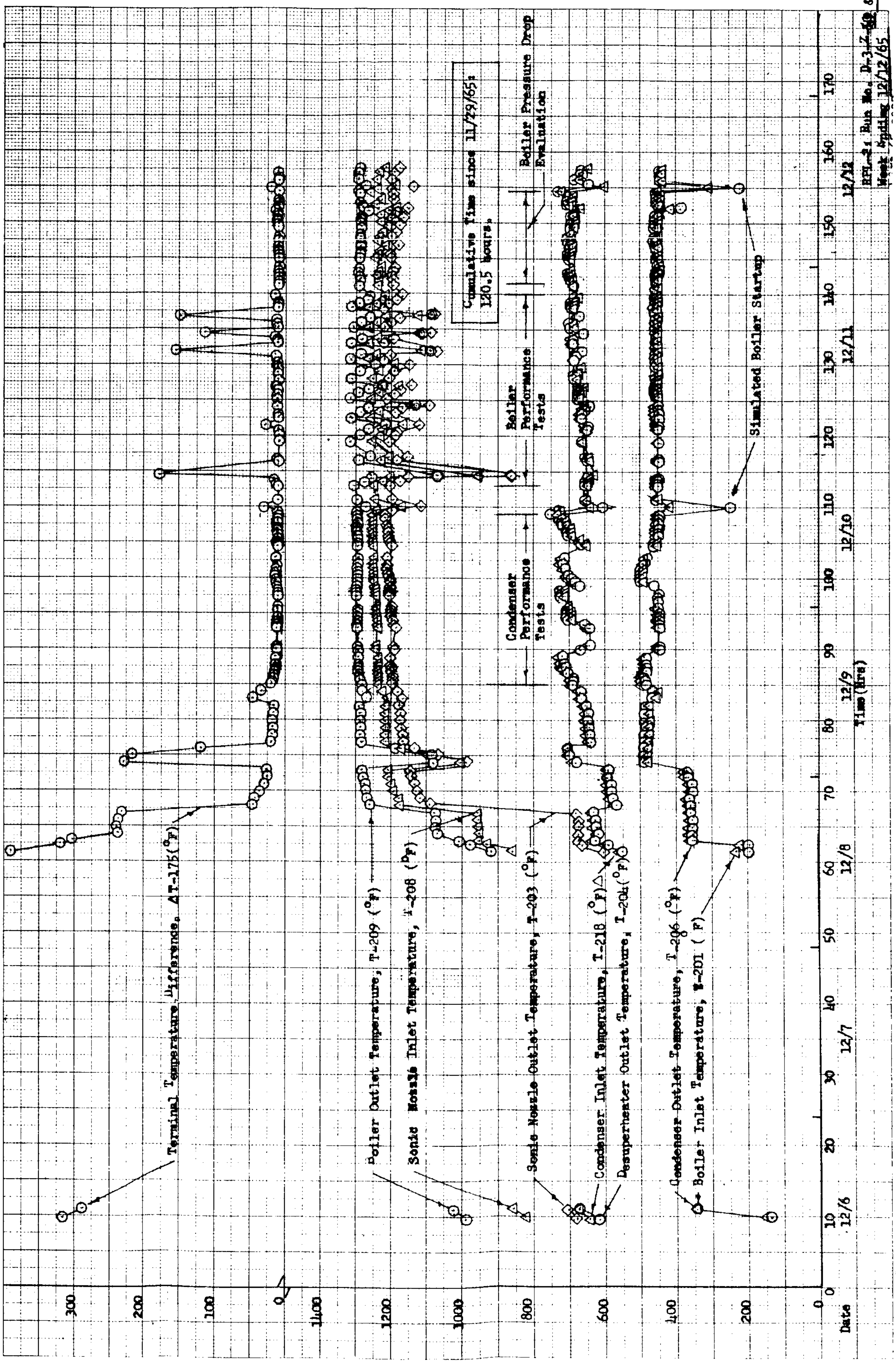
Figure II-2



Hg Loop Temperatures - Run D-3-Z-47 and 48

B166-NF-1138

Figure II-3

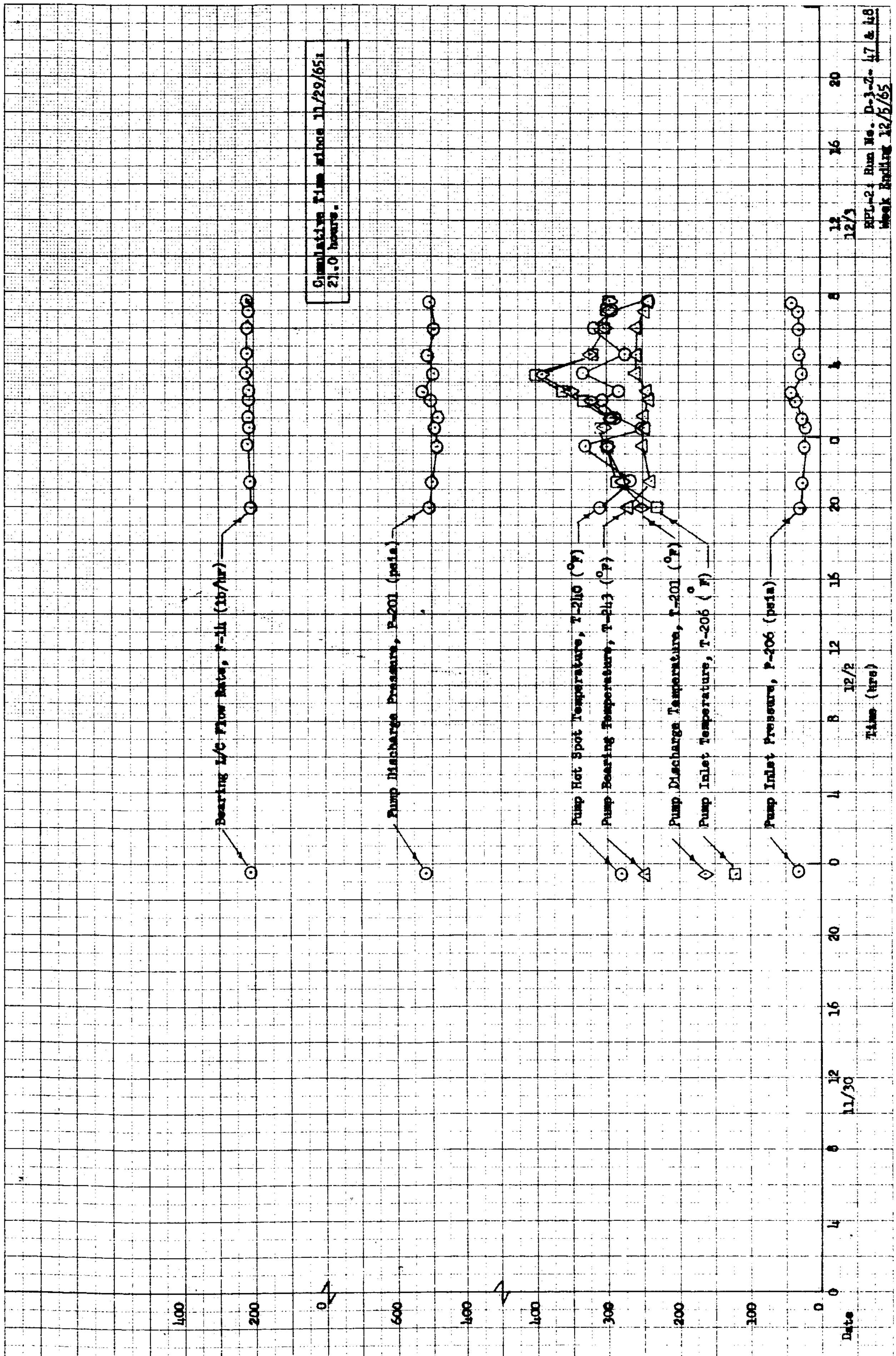


Hg Loop Temperatures - Run D-3-Z-49 and 50

B166-NF-1139

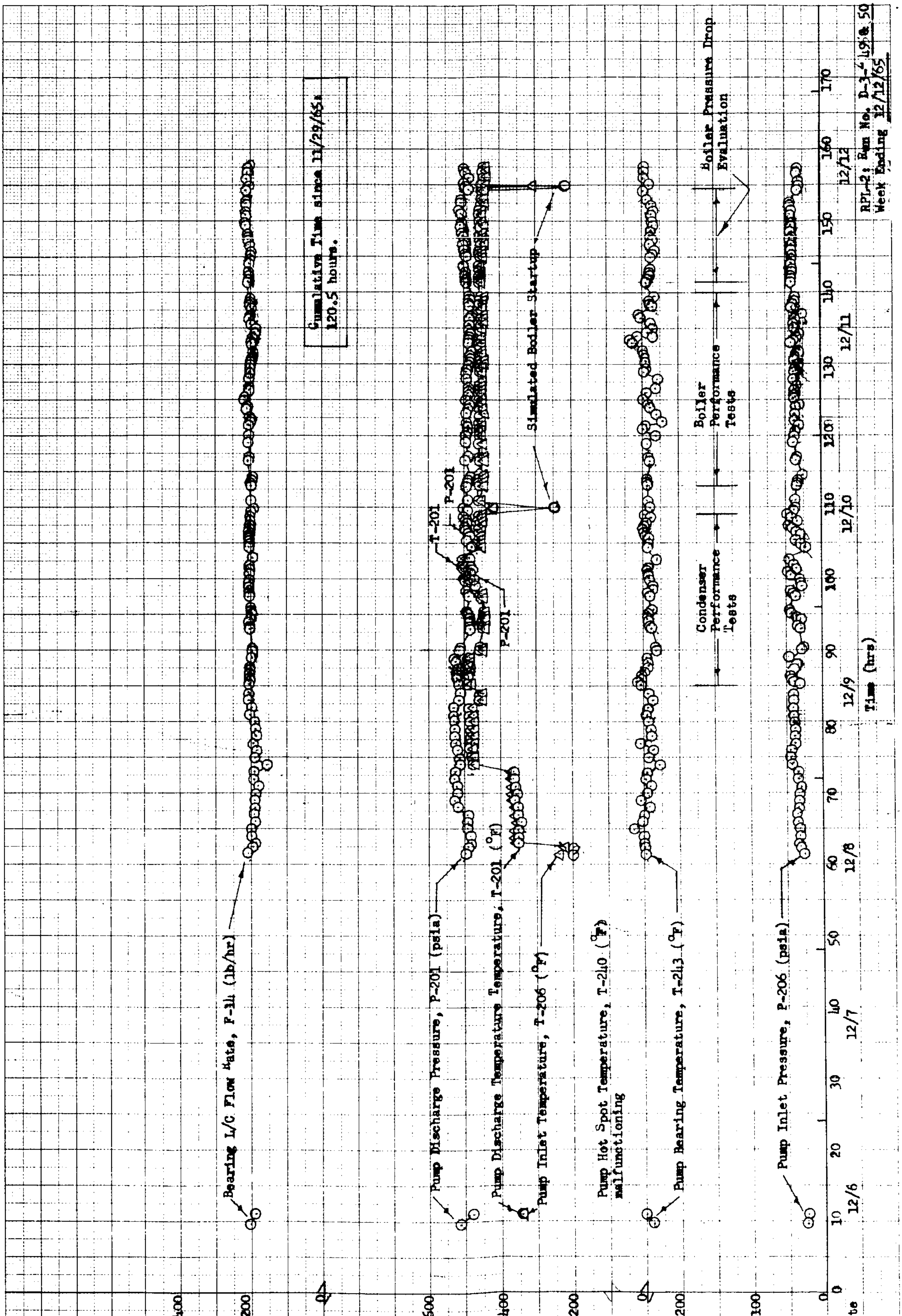
Figure II-4

B166-NF-1140



Hg Pump-Motor Assembly Performance - Run D-3-Z-47 and 48

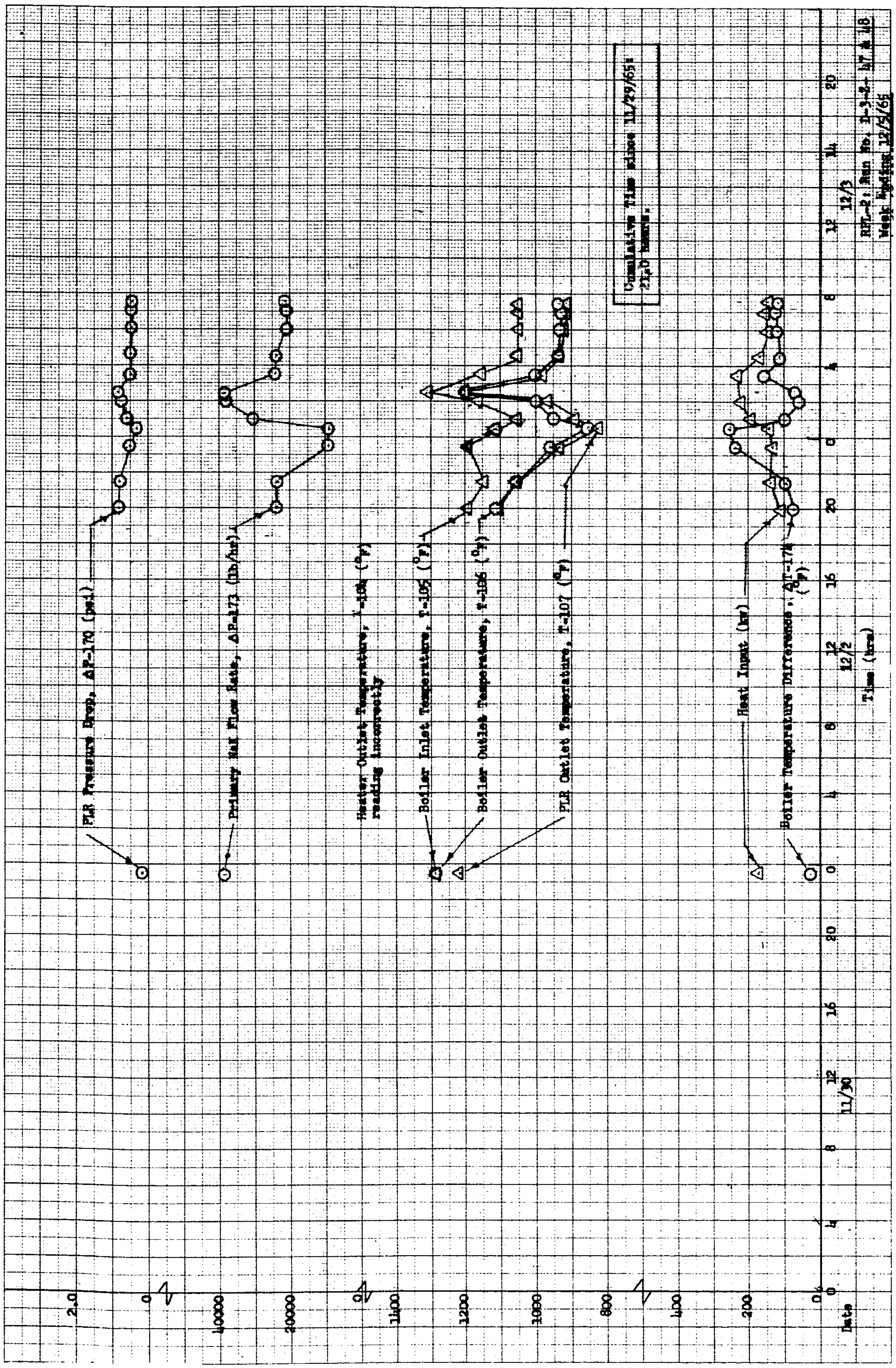
Figure II-5



Hg Pump-Motor Assembly Performance - Run D-3-Z-49 and 50

B166-NF-1141

Figure II-6



Primary Loop - Run D-3-Z-47 and 48

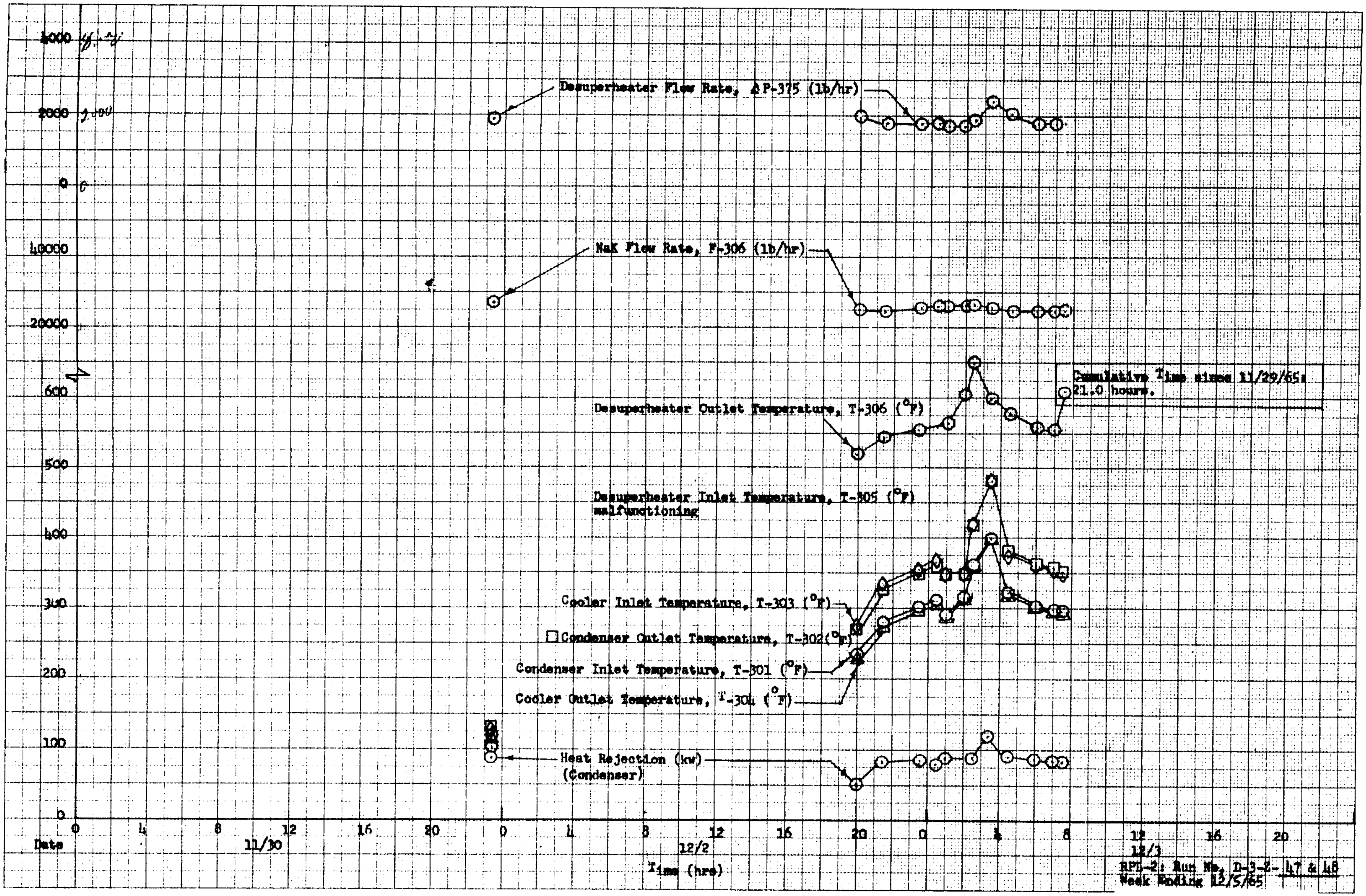
B166-NF-1142

Figure II-7

B166-NF-1143

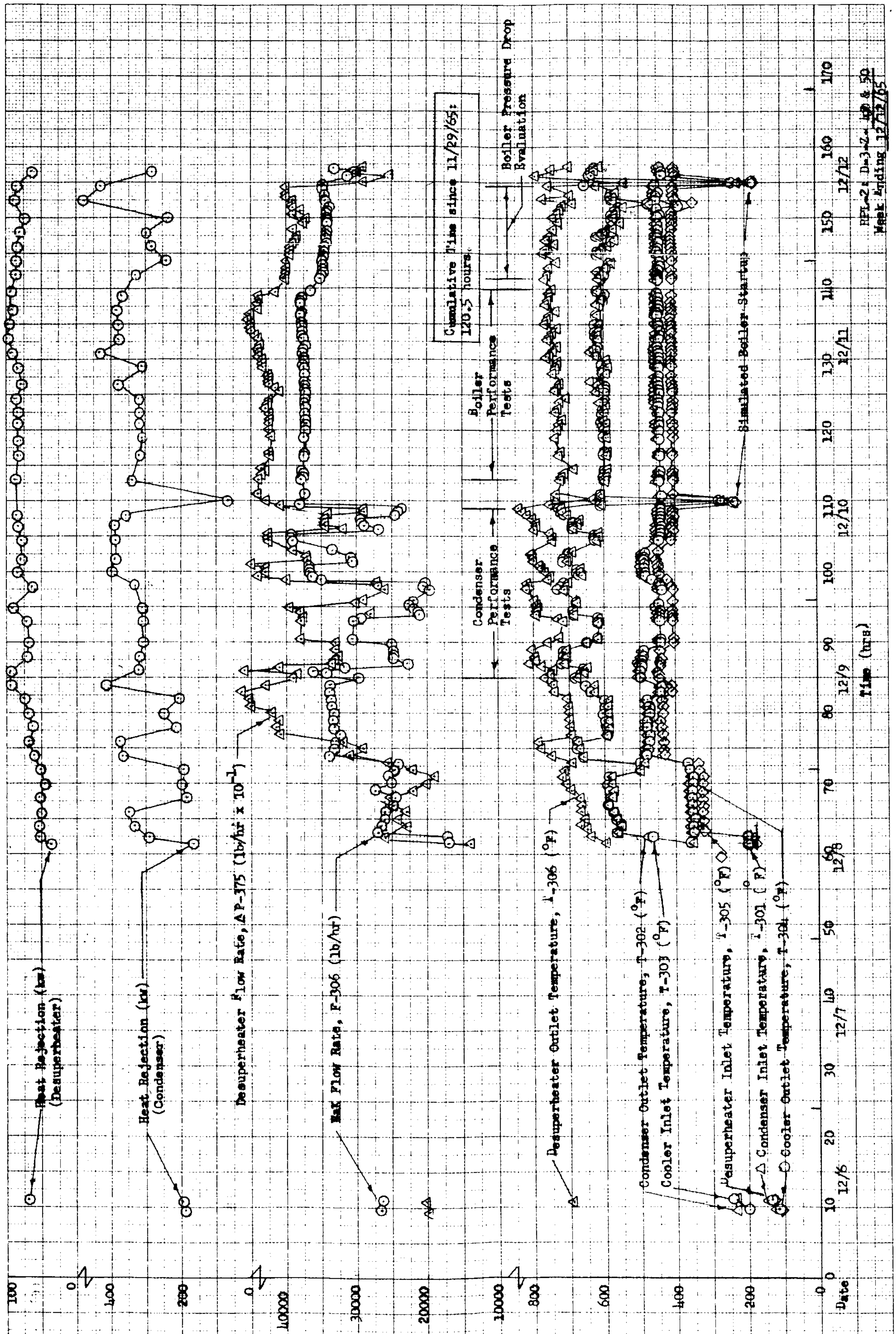
Primary Loop - Run D-3-Z-49 and 50

Figure II-8



Heat Rejection Loop - Run D-3-Z-47 and 48

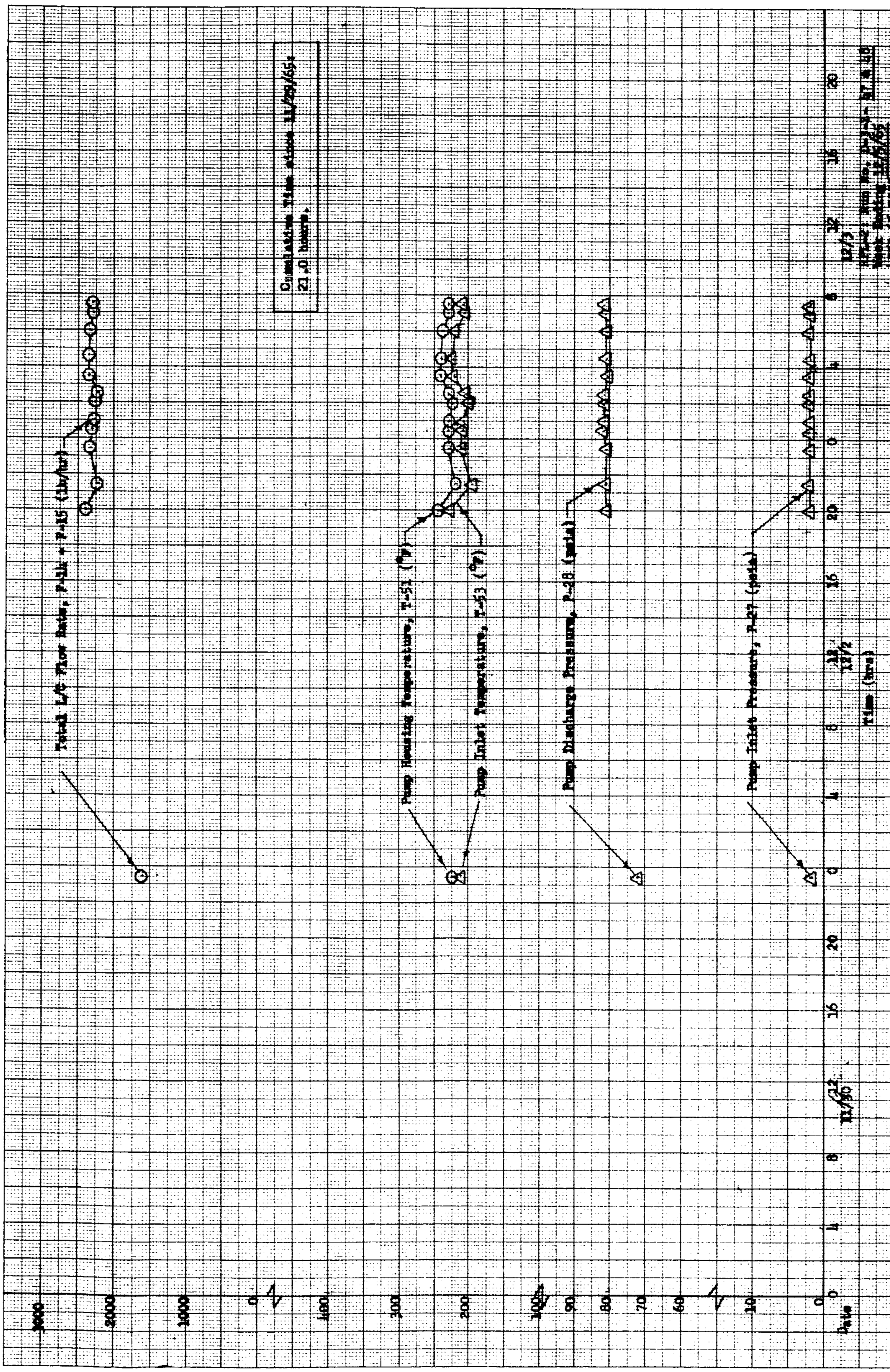
Figure II-9



Heat Rejection Loop - Run D-3-Z-49 and 50

B166-NF-1145

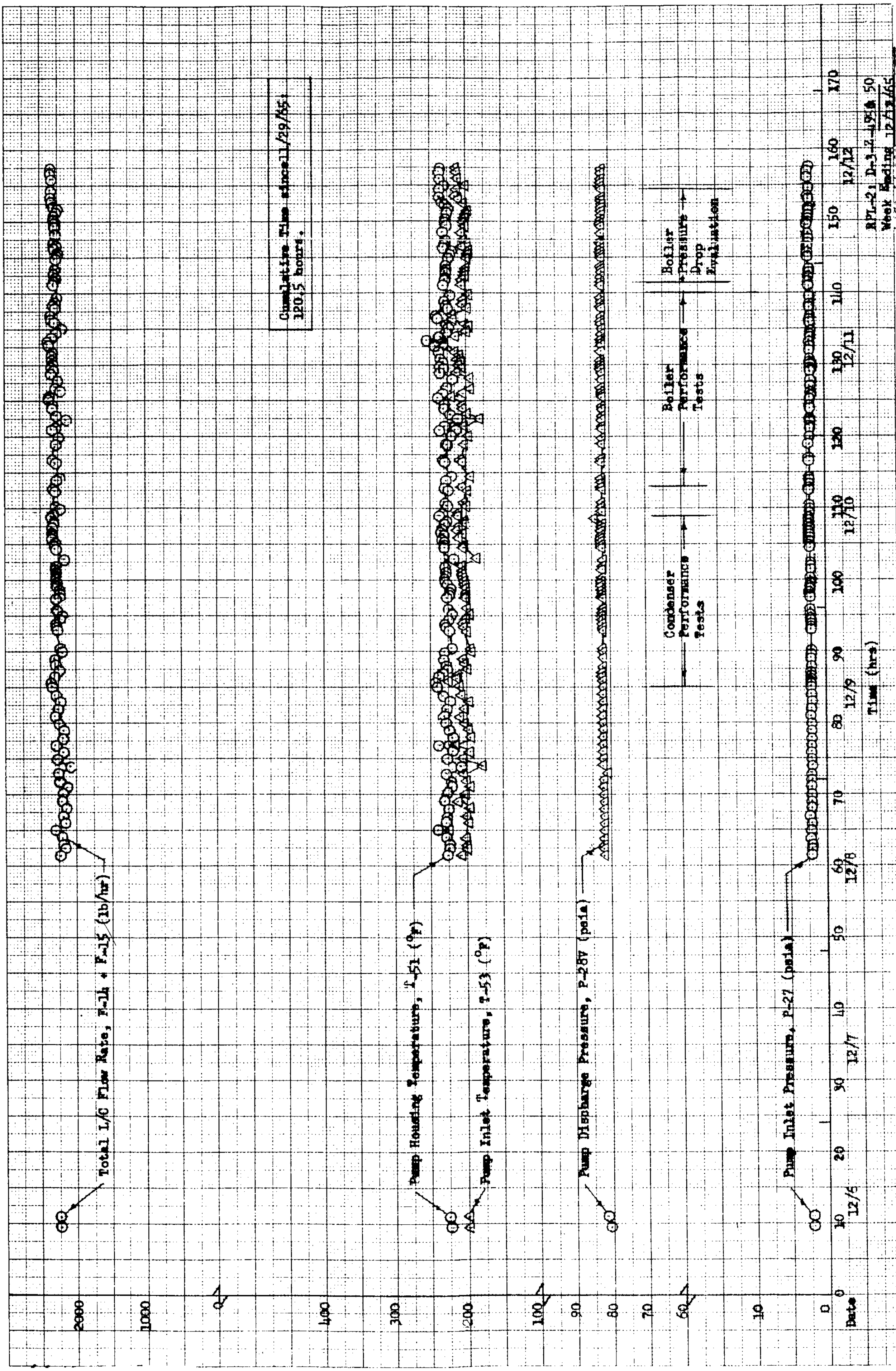
Figure II-10



L/C Pump-Motor Assembly Performance - Run D-3-Z-47 and 48

B166-NF-1146

Figure II-11



L/C Pump-Motor Assembly Performance - Run D-3-Z-49 and 50

B166-NF-1147

Figure II-12

III. POWER CONVERSION SYSTEM 1, PHASE I AND II (PCS-1/SL-1)

A. DESIGN AND ENGINEERING

During the report period, the engineering effort was devoted to the design of the installation of the tube-in-tube boiler and the design Phase II. Because of program reorientation, the Phase II design effort was terminated on 12 November 1965.

The design work performed for Phase II (January 1965 - November 1965), including the design of the tube-in-tube boiler installation, is reported in Ref. 7.

B. FABRICATION AND TEST OPERATIONS

PCS-1/SL-1 Phase I system testing was performed between 28 May and 21 July 1965. Following completion of the Phase I testing, the tube-in-tube boiler was installed and tested during the period of 1 September through 8 November 1965. Phase I and II testing is documented in Ref. 8.

C. TEST RESULTS AND ANALYSIS

Analysis of the system tests with the tube-in-shell boiler (-1) installed in PCS-1/SL-1 (Phase I) appears in Ref. 9. The following observations and conclusions were made*:

1. The boiler required 26 hours to condition. (Note: Hg temperature at the boiler outlet is $\leq 50^{\circ}F$ below the NaK temperature at the boiler inlet under rated PCS-1/SL-1 conditions.

2. The boiler performance at the rated PCS-1/SL-1 conditions was as follows:

Pressure drop - NaK side	8.5 psi
Temperature drop - NaK side	$170^{\circ}F$
Pressure drop - Hg side	80 - 110 psi
Hg temperature at boiler exit	$1285^{\circ}F$
Liquid carryover	7 - 10%
Boiler inventory	86 lb
Pressure oscillation at boiler exit	$\pm$ 12 psi

*A more complete analysis of boiler and condenser test results appears in Section VI,C of this report.

3. Condensation occurred on startup in the vapor line between the boiler and the turbine simulator for almost 800 seconds. The pressure drop in the line was 12.5 psi.

4. The primary loop pressure drop was 15 psi at rated NaK conditions (46,500 lb/hr, 1100°F to 1300°F).

5. The HRL pressure drop was 28 psi at a NaK flow of 39,500 lb/hr (rated) and a NaK temperature of 275°F to 450°F (less than rated temperature of 486°F).

6. The mercury and lubricant-coolant (L/C) PMAs use more power than expected.

7. The -1 flow control valve (Hg) performed about as expected.

8. The condenser was not tested at its rated conditions.

9. The condenser performance extrapolated to the PCS-1/SL-1 rated conditions would be as follows:

Pressure drop - NaK side	7.8 psi
Pressure drop - Hg side	(indeterminate)
Condensing pressure	18 psia
Condensing pressure fluctuation	0.6 psia
Hg subcooling	170°F

The PCS-1/SL-1 system performance with the tube-in-tube boiler installed was analyzed and reported in Ref. 10.

Some of the conclusions drawn from analysis of the data are as follows:

1. The system Hg flow increased by 0.6% when the primary-loop NaK temperature was decreased from 1330°F to 1270°F.

2. Stoppage of coolant flow in the heat rejection loop resulted in an emergency system shutdown, but the condenser inlet pressure did not exceed the emergency dump trip pressure of 30 psia by more than a couple of psi.

3. The radiator simulator loop did not perform as required because of the coarseness of the valve controls, the slow response of the air-cooled heat exchanger, and the performance of the NaK-to-NaK heat exchanger.

IV. POWER CONVERSION SYSTEM 1 (PCS-1) PHASE IV STEPS 2 AND 3

A. DESIGN AND FABRICATION

1. Step 2

The major objective of the PCS-1 Phase IV Step 2 design effort is to propose the designs for installation of the turbine-alternator assembly (TAA), the primary-loop NaK pump-motor assembly (NaKPMA), and the heat rejection loop (HRL) NaKPMA. All designs are based on the criterion of 10,000-hour endurance testing.

The two NaKPMAs and associated valving will be installed in series with the electromagnetic (EM) pumps but parallel to the line. This arrangement fulfills the threefold design requirements of (a) fluid purification prior to NaKPMA operation, (b) increased head rise to provide maximum off-design testing capability, and (c) continued system operation in the event of the NaKPMA failure. The lubricant-coolant (L/C) loop was redesigned to provide cooling for the NaKPMA cold traps.

2. Step 3

The major objective of PCS-1 Phase IV Step 3 design is to upgrade PCS-1 Phase IV to include the installation of (a) the start programer, (b) the transformer-reactor assembly (TRA), (c) the low-temperature coolant assembly (LCA), (d) the mercury injection system (MIS), (e) the auxiliary start loop heat exchanger, (f) the temperature control valve (TCV-1), (g) the auxiliary start loop isolation valve (SV-1), and (h) the rotary inverter. Criteria used in the design were the capability to simulate reference startups and to perform a 10,000-hour endurance test.

B. TEST OPERATIONS AND ANALYSIS

1. Documentation

The PCS-1 Phase IV Step 2 planning and analysis are nearly completed. The Test Plans and Test Reports are formulated for all component testing. These documents (Refs. 11 through 20) are in use to integrate the system and component testing of Step 2. The Test Specification will be completed in January 1966 and is identified as TM 4952:65-7-371 (Ref. 21).

The system capabilities were evaluated. Pressure drops, pump performance, and similar parameters, were determined for all loops to find the operational limits of the system. Figures IV-1, IV-2, and IV-3 present the limiting operating conditions for the primary, heat rejection, and mercury loops.

Figures IV-1 and IV-2 show the upper limit of the NaK flow rate for operation both with and without the EM pumps assisting the NaKPMAs. The limits using the EM pumps and the NaKPMAs simultaneously are only approximate because of a lack of data on EM pump head-vs-flow characteristics as a function of input power.

Figure IV-3 shows the relationship between mercury-loop flow rate and required NaK conditions. The relationship is based on maintaining a positive boiler pinchpoint temperature difference. The maximum mercury flow rate of 13,000 lb/hr is based on an upper stress limit of 300 psia (for 10,000 hour life capability) at the boiler outlet.

Operating envelopes for all components have been established. Each envelope includes operating limits that appear as boundaries on the envelope. A component is capable of operation at any condition within its operating envelope. The component envelope are presented in Ref. 22.

2. Test Objectives

The primary objective of PCS-1 Phase IV Step 2 testing is to acquire system performance data. System tests will investigate:

- Performance of the redesigned TAA
- System pressure balances
- System stability
- System efficiencies
- Parameter variations about the system design point
- Mercury inventory loss effects on the system
- System-limiting operating conditions
- Radiator simulation characteristics
- Lubricant-coolant temperature variation effects
- Startup characteristics.

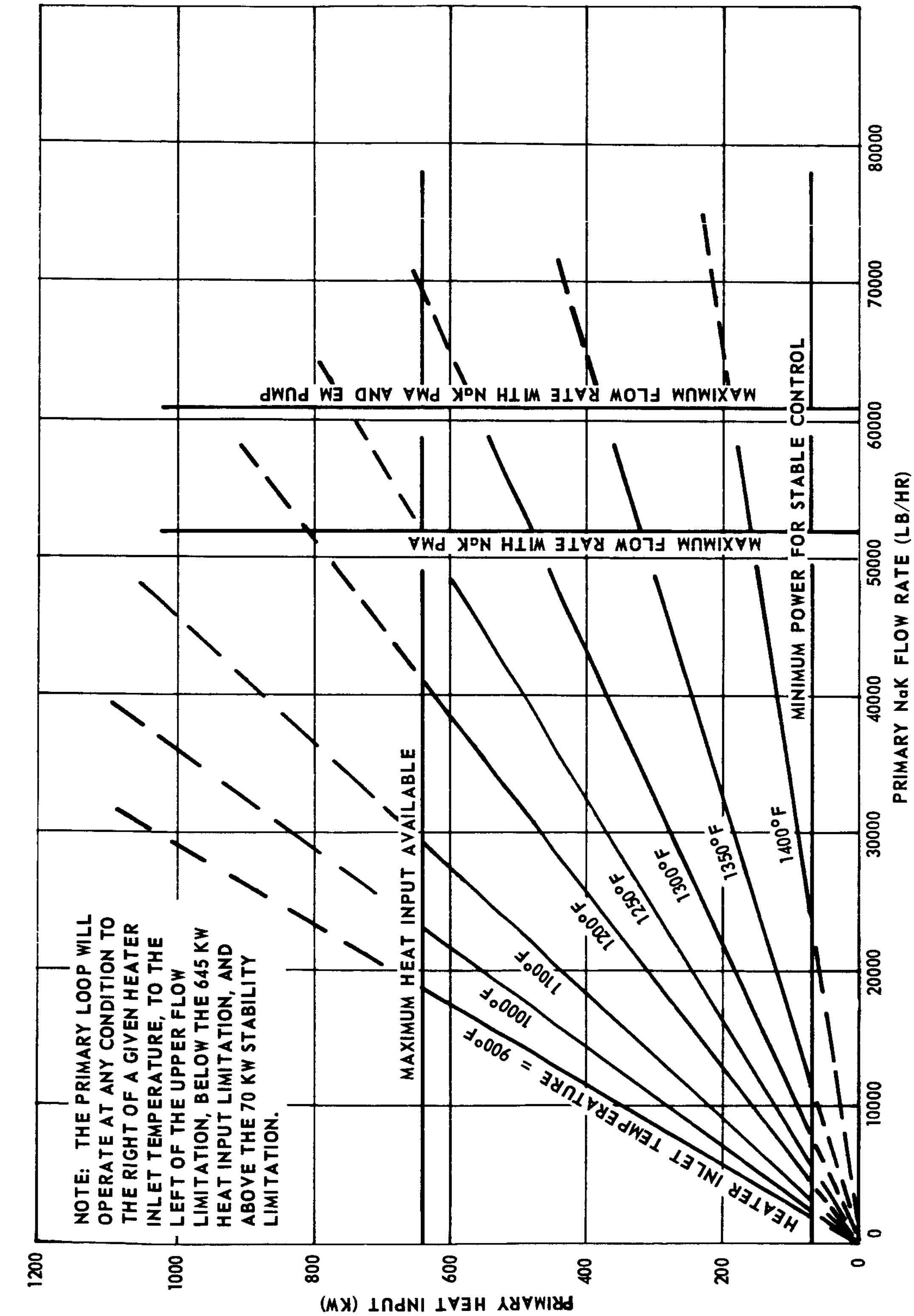
Component evaluation is also part of the Step 2 testing. Tests of the redesigned TAA will be performed to evaluate its performance at design and off-design conditions. The testing will also determine the integrity of the mechanical design changes and will investigate any functional degradation.

Tests on the electrical controls will provide data on the voltage regulator and speed control system. The characteristics to be determined are (a) speed-control stabilization requirements, (b) voltage and speed vs load and power factor, and (c) voltage and speed transient response for various operating conditions.

Tests on the mercury flow control valve are designed to provide data on the valve performance under actual working conditions. The tests will show the flow characteristics as functions of pressure drop and valve position.

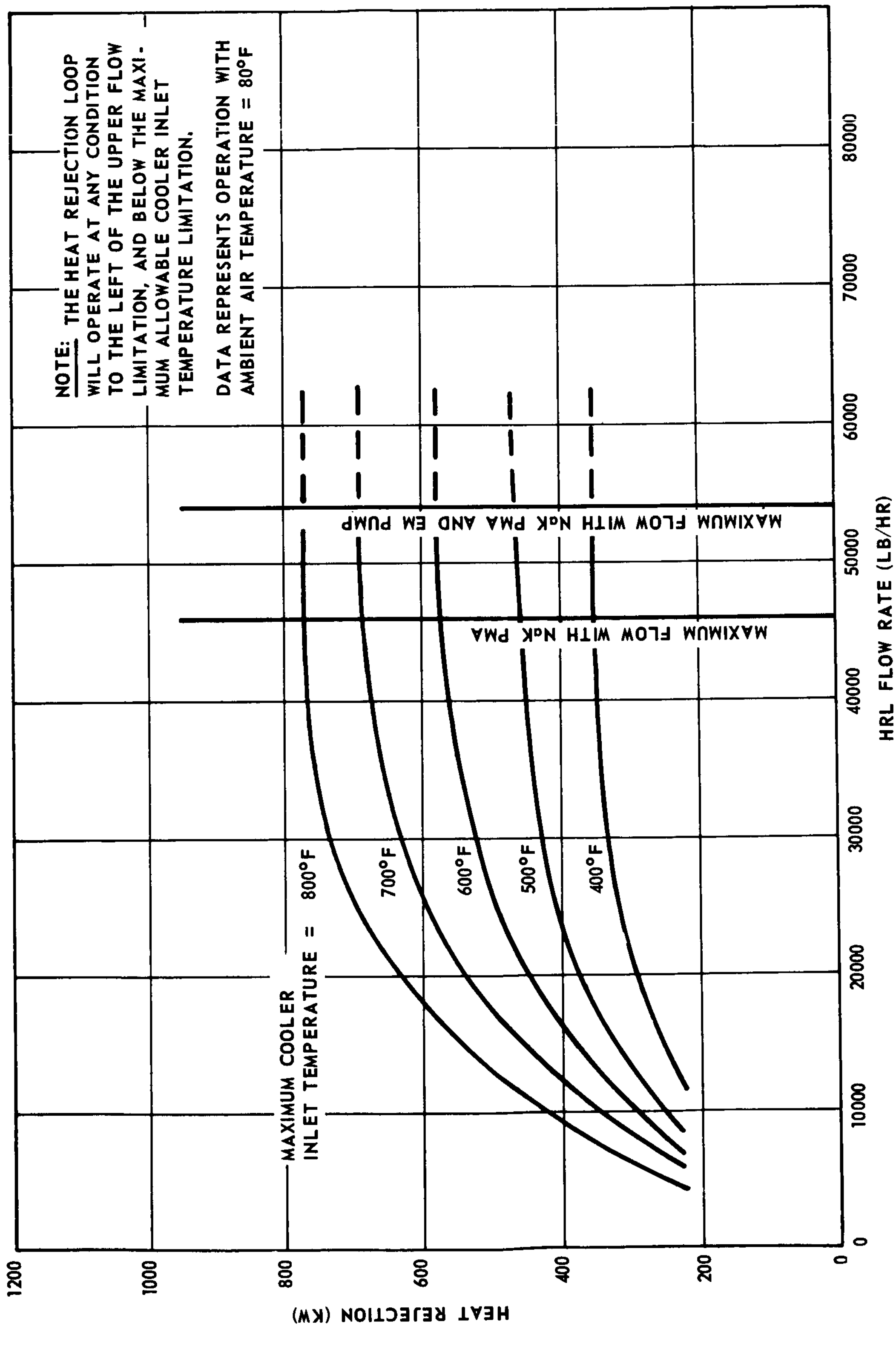
Tests on the Hg PMA will provide further performance data under actual working conditions. Data to be obtained are bearing performance with the bearing lubricant bypass flow eliminated, and measures of any possible performance degradation with time.

Tests on the NaKPMAs will indicate their performance when integrated into a system. Specific tests will investigate (a) head-capacity characteristics, (b) minimum allowable L/C flow rate, (c) maximum L/C temperature, (d) startup characteristics, and (e) any possible performance degradation with time.



Primary Loop Operating Envelope - PCS-1 Phase IV Step 2

A166-NF-1183/A

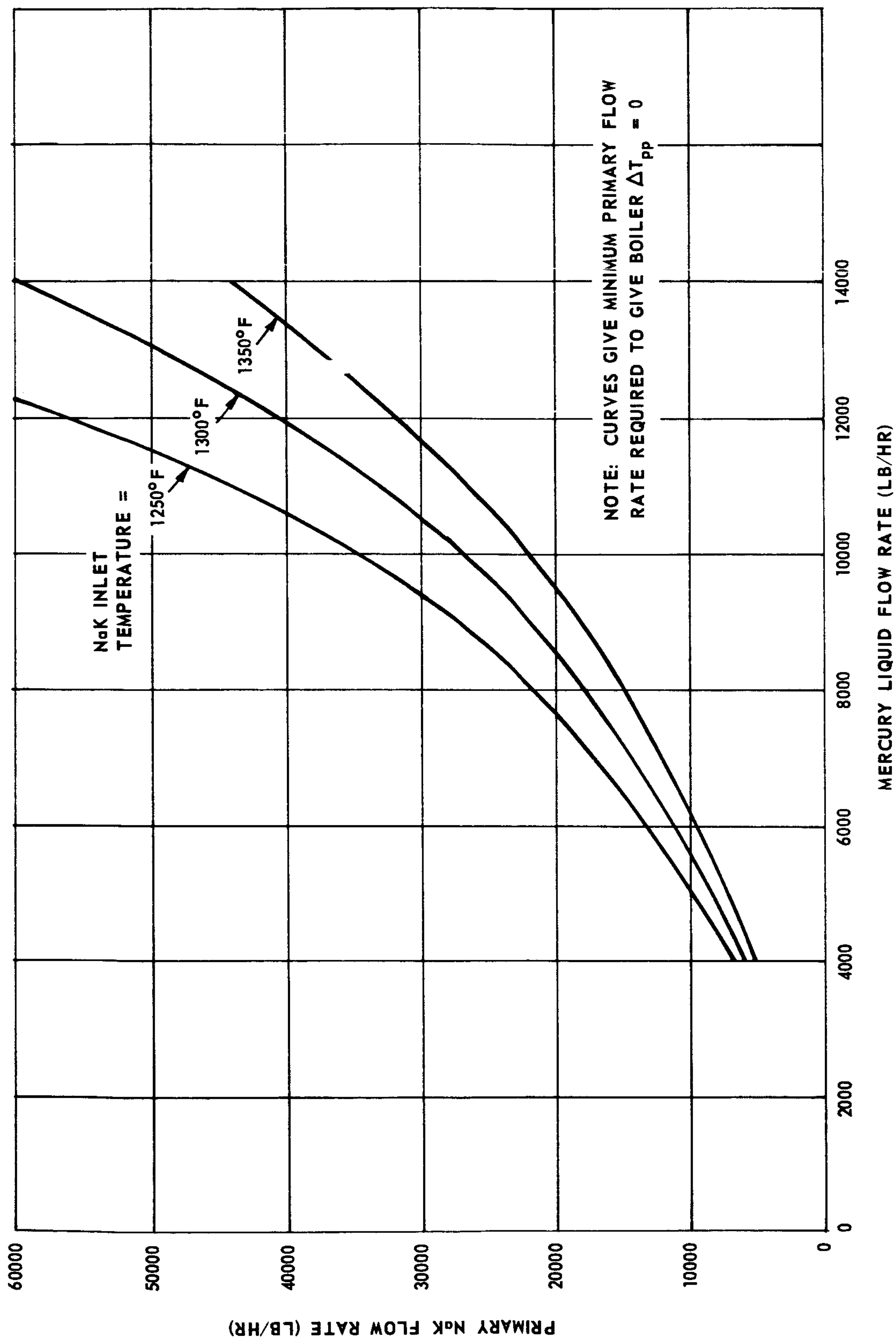


Heat Rejection Loop Operating Envelope - PCS-1 Phase IV Step 2

A166-NF-1184/A

Figure IV-2

A166-NF-1185/A



Mercury Loop Operational Limits to Maintain Positive Boiler Pinchpoint Temperature Difference - PCS-1 Phase IV Step 2

Figure IV-3

V. POWER CONVERSION SYSTEM G (PCS-G) PROJECT

During the period 1 July to mid-September, activities on this project included a configuration study for the power conversion system, generation of test-support equipment (TSE) design requirements, and a critical evaluation of coordination agreements that had evolved within the SNAP-8 program since 1961. In September it was decided to suspend activities in this area pending a decision to proceed with the SNAP-8 Continuation Program. The information generated was assembled in the "Interim Report on First Integrated System Test" (Ref. 23).

Activities during the remainder of this period were limited to the liaison necessary to maintain the option of instituting a SNAP-8 Continuation Program.

A. NUCLEAR COORDINATION

Coordination with the nuclear-system contractor, Atomics International, was confined to communications activities. Meetings were held both at Atomics International, Canoga Park, and at Aerojet-General, Azusa, to review and exchange information on subjects including:

1. Post-mortem examination of the SNAP-8 Experimental Reactor (S8ER).

2. Progress on the modification to the Ground Prototype Test Facility (Building 059 AEC, Santa Susana Field Laboratory).

3. Test progress and results from the system test loop and rated power loop 2 tests at Aerojet.

4. Schedule comparison and compatibility review as a part of preparation for resumed efforts on the joint systems test.

During the report period, an evaluation was made of the coordination agreements which had evolved between Aerojet and Atomics International within the SNAP-8 Program since 1961. As a result of the evaluation, a revised set of coordination procedures was prepared.

B. PCS-G DESIGN

A configuration study was undertaken to derive a concept that allowed greater adaptability to potential missions, both manned and unmanned. The criteria established as guidelines for the concept are as follows:

1. The basic SNAP-8 four-loop concept will be utilized.

2. SNAP-8 technology developed to date and being developed as part of the basic SNAP-8 Development Program will be utilized.

3. Components will be of modular design.

4. Components will be based on the SNAP-8 -1 design.

5. The PCS will be a complete package including all instrumentation hardnesses and TSE piping interfaces that will be located at the perimeter of the package.

6. Structural criteria will conform to NASA Specification 417-2.

7. The design will include both manned and unmanned application factors.

8. The design will be flexible to permit different potential applications (including instrument-rated applications).

9. Provision will be made for maximum accessibility for maintenance during testing and for manned-mission applications.

10. Restart capability should be provided as an integral part of the PCS development hardware.

Three basic configurations were reviewed: conical, cylindrical with center core access, and rectangular module. The results of this study are summarized on Table V-1. From these results the rectangular configuration was recommended and is shown in Figure V-1. This study is detailed in a technical memorandum (Ref. 24) prepared during the report period.

C. PCS-G TEST SUPPORT EQUIPMENT

A preliminary compilation of the basic TSE requirements was prepared, the TSE general design criteria were established, and preliminary conceptual designs of many of the TSE systems were completed during this report period. The basic concepts and design criteria will be applicable to future TSE, and therefore, can be used as a basis for further TSE development.

The necessary documentation for anticipated test operations of PCS-G and liaison coordination with the nuclear system (NS) contractor is being prepared. This documentation will accomplish the following:

1. List the test objectives.

2. Define the scope and magnitude of the test program to permit the required long-range planning and estimating.

3. Establish the basis for the TSE and facility requirements that must be met to satisfy the objectives and operational requirements of the test program.

4. Establish the basis for any PCS-G requirements that are dependent upon operational restraints.

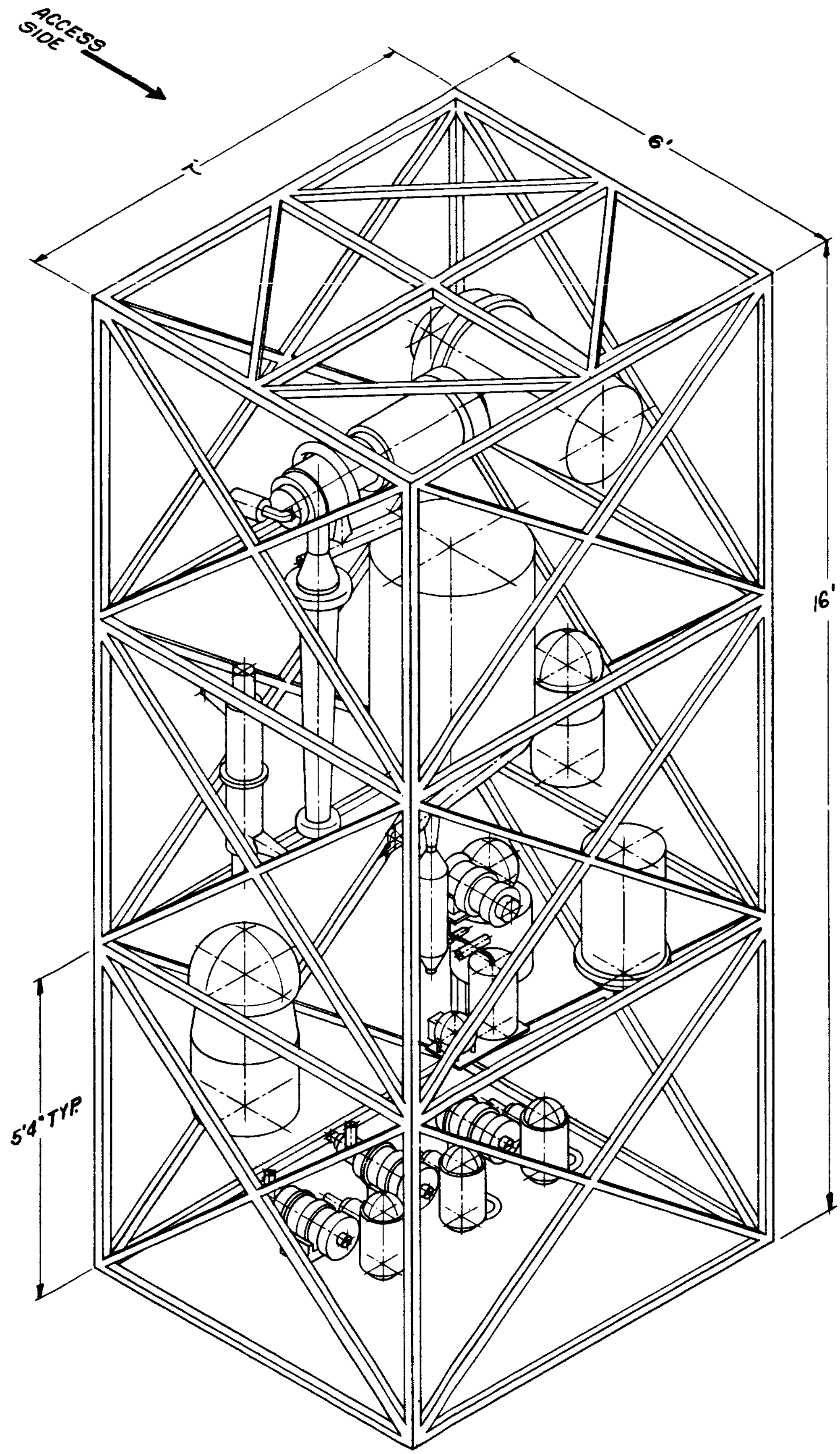
5. Establish the criteria for more detailed test documents required for the PCS-G test program.

TABLE V-1

PCS-G CONFIGURATION SELECTION

	Selection Criteria	Conical	Center Access	Rectangular
1.	Fits through GPTF 13 x 17 ft access (Fits through GPTF 10 ft dia access)	Yes (Marginal)	Yes (No)	Yes (Yes)
2.	Access for component removal	Yes	Yes	Yes
3.	Direct mission applicability	Unmanned only	Manned only	Manned and unmanned
4.	Relative weight*	Low	High	Median
5.	Adapts to multiple PCS arrangements	Limited	Limited	Yes

*Based on equal capability for supporting NS launch loads



PCS-G Configuration Study - Rectangular Concept

Figure V-1

VI. COMPONENTS

A. TURBINE-ALTERNATOR ASSEMBLY (TAA)

The period from July through December 1965 has been one of significant technical progress. As a result of a comprehensive failure analysis of the turbine-alternator assembly failure in RPL-2 on 22 June 1965, four specific problem areas requiring turbine redesign were identified. These problems were considered resolved, and the turbine was redesigned. In addition, the inlet mercury vapor filter was redesigned, and the method of instrumentation installation was improved. Examination of the failed TAA components and analysis of the test data showed that the unit had operated under severe conditions before failure.

Three dimensional thermal maps were made of the first-, second-, third-, and fourth-stage turbine nozzles, and a stress analysis was completed. The new parts (second-stage nozzle and shroud, visco seal runner, and smaller thrust reduction seal) used in the turbine modifications were fabricated for TAA 2/3, and the unit was assembled and installed in the PCS-1 Phase IV test facility for Step 2 testing.

A study of the potential performance was made to determine the areas in which improvements could be made within the scope of the present turbine design. The results of the study are reported in Ref. 25.

1. Failure Analysis

Following the failure of the TAA in RPL-2, 22 June 1965, after 820 hours of operation, the turbine parts were carefully reconstructed, inspected, and analyzed to determine the modes of failure and recommendations made for redesign of the parts (Ref. 26). It was concluded that the primary cause of failure was the retaining ring for the second-stage labyrinth seal. This ring worked loose from its positioning groove and eventually jammed into the first-stage rotor tip-clearance area, breaking off blades which progressively caused failure of the first- and second-stage wheels and nozzle diaphragms of the turbine. Figure VI-1 shows a similar failure that occurred in the third-stage labyrinth seal.

2. Identification of Problems

As a result of several reviews of the turbine design and the failure analysis, the four problem areas in the turbine which needed correction were identified. These areas are described as follows:

a. The labyrinth seal moved during periods of low pressure differential, particularly during deceleration. Axial clamping was required to dynamically dampen the motion of the ring to prevent the labyrinth seals from bouncing and causing excessive relative motion between the labyrinth seal and its retaining device.

b. A problem existed in the first-stage nozzle block retention method. Welding of Stellite 6B nozzles to a 316 SS housing created excessive thermal stresses in the weld joint causing failure of the material in the weld-affected zone. These weld cracks allowed the nozzles to become loose; as a result, they leaked and became a hazard to the first-stage rotor.

c. Two problems existed in the second-stage nozzle diaphragm assembly. The major one was that the transient thermal stresses between the nozzle shroud and nozzle diaphragm were greater than the yield strength of the Stellite 6B material, thereby causing failure of the one-piece transition joint between the shroud and diaphragm. Secondly, the shape of the notches in the nozzle shroud bearings, used for centering purposes, was such that the stress concentrations were too high for the notch resistance factor of Stellite 6B, which is very low.

d. A problem associated with the turbine material was determined. The Stellite 6B material was found to transform from face centered cubic (FCC) to hexagonal close packed (HCP) crystalline structure. As a result of the transformation, the physical and mechanical properties varied.

e. A problem associated with cavitation damage in the space-seal visco pump limited the life and sealing capability of the visco pump.

More extensive discussions of the problem areas and the solutions are found in Refs. 27 and 28.

3. Solution to Problems

The problems described above were studied, several methods for correction were considered (Ref. 27) and the solution determined.

a. The labyrinth seal dynamic problem was resolved by use of an iron plated, Inconel 718 tapered snap ring in the first stage and PH 15-7Mo tapered snap rings in the interstages. They provide an axial clamping force on the labyrinth seals which changes the free floating labyrinth concept to a semifixed design. The snap ring is locked in place with a 316 SS centering washer.

b. The first-stage nozzle block retention method (Stellite 6B welded to 316 SS) was replaced by an interim design that employs the same nozzle block modified to float between the inlet housing and a 316 SS retainer which is welded to the 316 SS inlet housing. Another higher performance design, having individual Stellite 6B nozzle vanes free floating in a 316 SS nozzle block, was completed for future improved models.

c. The second-stage nozzle assembly was redesigned. In this new design, the diaphragm and shroud are separate pieces joined radially, similar to the method used in the third and fourth stages. The shroud is made from PH 15-7Mo which has a coefficient of thermal expansion of 6.1×10^{-6} in./in./°F; the diaphragm is made from HCP Stellite 6B which has a coefficient of thermal expansion of 8.3×10^{-6} in./in./°F. This feature allows the diaphragm and shroud assembly to be assembled with a nominal 0.006 in. clearance that closes up from line-on-line to 0.002 in. interference during steady-state operation. Of significance is that it allows the nozzle vanes and diaphragm to expand independently, thus eliminating excessive transient stresses in the shroud and diaphragm. In addition, the nozzle vane clearance leakage during steady-state operation is reduced. Turbine performance improvement of 0.3% is expected from this change (Ref. 25).

d. The mercury vapor inlet filter was redesigned and modified to replace the Conoseal joints with structural weld joints. The filter uses standard pipe weld fittings and reducers.

e. In order to reduce the cavitation damage, the visco pump rotor material was changed from Greek Ascolloy to Stellite 6B (HCP) which has known superior cavitation damage resistance. In the Model A turbine (P/N 098500-1) the visco pump stator material (1010 steel) was not changed. However, in future models, the stator material will be changed to a cavitation resistant material that will require extensive redesign and modification of the composite housing.

4. Three-Dimensional Transient Analysis

A review of the transient thermal conditions in the turbine was made resulting in necessity for a complete three-dimensional thermal analysis of the turbine nozzle assemblies. Results of this analysis and a corresponding stress analysis are shown in Refs. 29 and 30.

5. Turbine Performance Potential Study

This study was made to determine the physical changes that could be made to the turbine to improve its performance. The study was made in two parts. In the first part, the changes made to the machine to be tested in PCS-1 Phase IV Step 2 were examined. In the second part, the effects of additional changes (removal of thrust seal, change in rotor pitch/chord ratio, removal of nozzle leakage, etc.) that would be made on other units were examined.

Part one of the study showed that, if full mechanical effectivity of the changes is assumed, the turbine in PCS-1 Phase IV has a potential efficiency of 61.3% with zero liquid carryover, or 59.8% with 2% liquid carryover.

The improved turbine, in part two of the study, showed a potential efficiency of 66% with zero liquid carryover or 64.4% with 2% liquid carryover.

6. Alternator Assembly

The SNAP-8 alternators (P/N 094069, S/N's 481490 through 481510) have been completed at General Electric Co. and received by Aerojet. All units have successfully completed acceptance tests. The only discrepancy was in the temperature of the 180° (arc) bus ring which exceeds the specified temperature (200°C) by 5°C. Since the bus ring is not insulated, the winding temperature established for insulation reliability does not apply.

The alternator final report will be completed in February 1966.

The preprototype alternator (P/N 094162, S/N 481488) removed from TAA 3/2, which failed in RPL-2, was returned to the General Electric Co., Erie, Pennsylvania for retest, disassembly, and inspection after accumulating approximately 900 hours of testing. The test and disassembly is complete and visual inspection of the parts showed no visual signs of wear or degradation. A final inspection report and performance analysis is forthcoming.

7. Bearing Test Program

A program to test the endurance characteristics of multiple remelt M-50 steel bearings lubricated by mix-4P3E (polyphenyl ether) is being performed by the SKF Industries, Inc., Research Laboratory. Endurance data collected from the first two groups tested in this program proved to be poor for a vacuum-remelted M-50 steel. These poor life data were interpreted as having resulted from an unfavorable trace element content in this heat of steel. The details are discussed in previous SNAP-8 Quarterly Reports (Refs. 31, 32, and 33).

As a result of these tests, the program was redirected and a second heat of steel equivalent to Aerojet Development Material Specification AGC 10354, Type 1 (air melted), Class 5 (five consumable electrode vacuum remelt cycles) steel was purchased. This heat had a known favorable trace element index, $\Theta = 2.5$ compared to $\Theta = 7.0$ for the first heat. Inner rings of size 309 (45 mm bore) test bearings were manufactured from the second heat under a revised program.

a. Baseline Fatigue Tests in Mineral Oil

Endurance testing on a 10-bearing group of size 309 bearings having inner rings made of 5th CVM M-50 material, manufactured from a second heat of steel selected for its known favorable trace elements, was completed. These are baseline tests in mineral oil (Socony Mobil DTE extra heavy) against which tests in mix-4P3E polyphenyl ether will be compared. Estimates obtained from the failure data indicate B_{10} life of 76×10^6 revolutions or 7.6 Bearing Catalog Life, verifying that this heat has endurance properties that are likely to be better than those obtained from the first heat of steel tested on this program.

b. Baseline Fatigue Test Analysis

Baseline fatigue tests for a 10-bearing group in mineral oil were completed in June 1965, and the results have shown a satisfactory B_{10} fatigue life. However, when the summary of endurance data was reviewed in terms of time, it was observed that all three bearing failures occurred on one test head, number 035. A statistical analysis was performed to determine the probability of selecting all the "poor" bearings at random and assigning them to the same machine. The results of this analysis, shown by three separate estimates of the probability (P), indicate that three "poor" bearings out of ten bearings tested would all be assigned, by chance alone, to test head number 035, are:

(1) $\frac{1}{180} < P < \frac{1}{120}$, based on hypergeometric distribution per single sample of six or four (four test heads were used at the start of testing then increased to six).

(2) $P = \frac{1}{120}$, based on hypergeometric distribution applied to sequential outcomes in test of first sublot of ten bearings.

(3) $\frac{2}{100} < P < \frac{3}{100}$, based on simulated testing of 200 sublots of 10 bearings each following bearing sampling and allocation patterns similar to the actual tests.

c. Fatigue Tests in Polyphenyl Ether, Mix-4P3E

During the first week in July 1965, the mix-4P3E oil schematic of the new machines, test heads, test procedures, method of lubrication, and a new schedule were reviewed. As a result of this review, an oil filter has been added to the oil loop; the outer ring operating temperature was established at 240°F $\pm$9°F; the test oil will be heated before actual tests will begin either by circulating the oil first in the loop, or, if this is unsatisfactory, an oil heater will be added to the system. Observations will be made if there is excessive foaming of the polyphenyl ether, and if the lubricant has a proper flow pattern.

Based on the baseline fatigue test analysis of estimated probability numbers, the program was redirected. Test head number 035, used in the baseline tests in mineral oil, was metrologically examined for the presence of any factors that might have influenced the failure of test bearings. Following the examination, the test head is being used for other standard SKF endurance testing; a record is being kept of bearing performance; and a statistical analysis will be made to establish probability of the influence of this test head on the occurrence of failures.

As a result of statistical analysis discussed above and narrowing of the one-sigma confidence limits, the number of bearings used in this phase of test program was increased from 10 to 12. This will equalize the probability chance for each bearing and each test head and increase the testing efficiency (each machine accommodates four test bearings). Test head number 035 was eliminated from these tests.

The testing outline now is as follows:

Group	No. of Bearings	Material M-50	Lubricant	Outer-Race Temperature	Remarks
1	10	5th remelt (new heat)	Socony Mobil DTE extra-heavy oil	203-221°F	Baseline tests in mineral oil (completed)
2	12	5th remelt (new heat)	Mix-4P3E	231-249°F	

Details of the complete program have been reported in Ref. 34.

After an initial checkout of the new stainless steel mix-4P3E test system, testing has started on this group of bearings. Inspection of two bearings after the first four hours of testing showed no signs of wear or lubrication distress.

After 20 hours of operation it was determined that the oil could not be heated sufficiently by friction, and an oil heater was added to the loop; only two test heads, instead of six, could be run with the lower flow rate of cold mix-4P3E (80 to 100°F).

The program encountered further difficulties resulting from an excessive oil leakage through the test-equipment labyrinth seals. This oil leakage, which is considered "normal" for inexpensive mineral oil tests, is not tolerable for the mix-4P3E tests. The seals were redesigned; however, this resulted only in a temporary decrease in oil leakage. Three solutions were evaluated to eliminate or bypass this problem: (1) continue development of sealing methods until a satisfactory seal is found, and then continue testing; (2) continue testing with the excessive leakage which would result in a loss of approximately 30 gallons of mix-4P3E; and (3) connect the mix-4P3E lubrication system to the slave bearings also. The latter solution was followed. Naturally, the oil leakage will not be resolved; however, the mix-4P3E will not be diluted with mineral oil, and can be collected and put back into the system. Only two machines, instead of three, can be operated as a result of this change (limitation of the lubrication system) and testing time will be lengthened.

Based on this, the testing will start in mid-January 1966 and continue until mid-March 1966; the formal report is scheduled to be submitted by SKF by the end of April 1966.

8. Bearing Material

Fourteen hundred pounds of bar stock (forged M-50 tool steel, 5 in. square with rounded corners) were ordered from Latrobe Steel Company; Latrobe, Pennsylvania, in accordance with Development Material Specification No. AGC-10354, "Requirements for AISI M-50 Bearing Steel," with changes in chemical composition and gas content and microinclusion rating. The new requirements are shown under the "Specified" column in Table VI-1. Classification of the material is Type II (vacuum-induction melted), Class 3 (three consumable electrode vacuum remelt cycles).

By the end of July 1965, the first phase (vacuum-induction melting) of making the steel had been completed. Analyses of the chemical composition and gas content were conducted of the vacuum-induction ingot. The results of the analyses (see "Reported" column of Table VI-1), show that the chemical composition and gas content are within specified limits, except for aluminum (reported 0.03% against specified 0.01% maximum).

The trace-element indexes (or composite trace-element abundance) of aluminum, copper, and nickel were calculated; a lower content of copper (reported 0.01% against specified 0.08% maximum) practically eliminated the effect of the higher content of aluminum.

Determination of the trace-element index (θ), which is a relative measure of a "good" or a "poor" heat of steel from a standpoint of a high or a low bearing fatigue life of steel, is as follows:

$$\theta = \frac{Al}{\overline{Al}} + \frac{Cu}{\overline{Cu}} + \frac{Ni}{\overline{Ni}}$$

where Al, Cu, and Ni are percent content of each element; $\overline{Al}$, $\overline{Cu}$, and $\overline{Ni}$ are mean percent content of each element.

A trace-element index for this material, based on past experience of 52100 bearing steel and on the presently conducted multiple remelt M-50 bearing steel endurance test program, is assumed to be:

$$\theta = \frac{Al}{0.015} + \frac{Cu}{0.060} + \frac{Ni}{0.070} \leq 4.0$$

The trace-element index in accordance with the specified chemical composition (Table VI-1) is $\theta = 3.0$. The trace-element index for the vacuum-induction melt of the first heat of steel (reported chemical composition is shown in Table VI-1) was as follows:

$$\theta = \frac{0.030}{0.015} + \frac{0.010}{0.060} + \frac{0.070}{0.070} = 3.167 < 4.0$$

which was acceptable.

Between the second and third (final) consumable-electrode-vacuum-remelt cycle, the ingot was inadvertently overheated and, as a result, it broke apart during the forging operation. The material was scrapped, and a new heat was made without any difficulties encountered either in obtaining proper chemical composition or in forging operations (as was experienced in previous heat of steel).

Analysis of the chemical composition and gas content was conducted of the vacuum-induction, and the first consumable-electrode-vacuum-remelt ingots (Table VI-2).

The calculated trace-element index of aluminum, copper, and nickel for the first consumable-electrode-vacuum-remelt ingot of the second heat of steel, which should remain relatively the same after two additional remelt cycles is:

$$\Theta = \frac{0.010}{0.015} + \frac{0.010}{0.060} + \frac{0.060}{0.070} = 1.692 < 4.0$$

which is acceptable. There is almost 50% improvement of the trace element index for the second heat of steel. The making of the steel has been completed through the third remelt cycle and the last forging operation to size (bar 5 inches square with rounded corners). All the physical, chemical, and inclusion rating tests were performed. The material shipment date to Aerojet has been confirmed for mid-January 1966.

B. PUMP-MOTOR ASSEMBLIES

1. NaK Pump-Motor Assemblies

During the time period covered in this report, the following technical achievements were realized:

Two NaK pump-motor assemblies, P/N 093200-13, S/N A-4 and S/N A-6, were completed and installed in PCS-1 Phase IV.

One NaK pump-motor assembly (P/N 093200-13, S/N A-5) successfully completed 3028 hours of endurance testing. Testing began on 22 July 1965. This LNL-3 installation represented the first use of the fabricated (rather than cast) pump housing, and was the culmination of the effort to replace the leaking castings with a sound, reliable pump housing. The PMA operated continuously from late July through 6 December 1965.

Two PMAs (P/N 096647-1, S/N A-5, S/N A-2) were completed and shipped to LeRC.

a. NaK PMA Testing in LNL-3

The test objectives for LNL-3 were to:

(1) Conduct a 3000-hour endurance test at the SNAP-8 primary loop conditions to determine time-dependent variables.

(2) Perform a series of starts and stops at ambient temperatures (500°F and 1170°F) to demonstrate adequate restart capabilities.

(3) Perform a series of head-capacity and cavitation tests.

(4) Obtain thermal maps for the PMA at primary loop and heat rejection loop conditions.

(5) Perform a series of tests to corroborate the torque-speed curves for the PMA operating with NaK.

The sequence of tests and the monitoring thereof can be found in Table VI-3.

Several series of start-and-stop tests were performed at ambient temperature, 500°F (HRL conditions) and at 1170°F (primary loop conditions). These tests were used to determine the required starting torques for the PMA and to demonstrate that increased starting torque was not manifested as the result of the lengthy period of this run. The start and stop tests were also used for correlating with the existing speed torque data from the original motor tests. Correlation of these tests is shown in Figure VI-2. Head capacity curves and PMA performance tests were performed during various phases of the 3000+ hour testing. The results are shown on Figure VI-3.

The NaK PMA (P/N 093200-13, S/N A-1/2) after completing 247 hours of test operation (described in Ref. 27) was stopped because the cast pump housing leaked.

The exterior of the PMA pump housing was cleaned of the heavy NaK oxide residual buildup to determine the area of leakage. The leakage occurred in a very porous area on the back of the casting in the cutwater area. This is the area where the previous pump housing casting leaked. The leakage was from a single crevice which appeared to be repairable. Efforts to repair the leak proved to be partially successful, and the PMA was operated for a short duration up to 835°F loop temperature before leakage re-appeared in another area approximately one-half inch away from the first. An effort was made to repair both of these leaks by welding a small plate to the pump housing. However, this proved unsatisfactory because of the confined space between the pump housing and the motor. The PMA was removed from LNL-3 on 13 July 1965 and decontaminated prior to disassembly.

A NaK PMA (P/N 093200-13, S/N A-5), which was the first PMA to incorporate the fabricated pump housing, was installed in LNL-3 on 19 July 1965. Testing commenced on 22 July 1965 with a series of start-and-stop tests to determine the restart characteristics. The PMA was heated to a loop temperature of 500°F at an average heating rate of 125°F per hour. At 500°F the PMA was started and stopped several times to determine whether any difference in restart capabilities occurred. None was observed. The PMA was shut down and allowed to cool to ambient temperature, then restarted on 26 July, heated to 500°F, then operated for 24 hours at this temperature.

Oxide contamination tests were performed on the PMA while the loop temperature was maintained at the 500°F steady-state condition. Plugging measurement showed an oxide level of 22 ppm, indicative of very efficient cold trapping.

On 27 July the PMA was heated to its operating temperature of 1170°F. Several starts and stops were accomplished without difficulty, indicating the ease of the restart and confirming the elimination of the restart problems discussed in the previous semiannual report (Ref. 27). The PMA continued operating during the month of August for 517 hours at which time the loss of several of the loop heating elements resulted in a drop of the loop temperature. The system was switched to 60 cycle power while two banks of new heaters were installed, increasing the loop heater capacity from 11 kw to 20 kw.

The PMA had continued to operate for a total of 607 hours when the 400 cps power supply failed. The PMA was switched to 60 cycle power and continued to operate for 96 hours while a new motor-generator (M-G) power unit was installed.

This PMA operated 24 hours a day, seven days a week during the month of September with the exception of one 6-hour period on 18 September 1965. The shutdown occurred when local storm conditions caused a failure in the power supply. A total of 714 hours had been accumulated during this month out of a possible 720 hours. The longest uninterrupted run was 23 days, from 27 August to 18 September 1965.

The PMA had operated 24 hours per day in LNL-3 for the complete month of October with the exception of 4.2 hours when a plant power failure caused a shutdown of the PMA. A total of 667 hours had been accumulated during the month out of a possible total of 672 hours.

The NaK PMA operated 24 hours per day in LNL-3 during the month of November for the complete month without interruption. The PMA continued to operate normally without shutdown 24 hours per day until the programed shutdown on the 6th of December 1965. The total operating hours through 7 December 1965 were as follows:

90 hours at 500-1000°F
188 hours at 1000-1100°F
2750 hours at 1100-1200°F
3028 total hours

There were 137 starts during the test program.

The accrued operating time of subcomponents in this assembly are:

Thrust bearing, P/N 097477, S/N A-3 - 3304 hr
Radial bearings inboard, P/N 095361 - 3304 hr
Radial bearings outboard, P/N 095362 - 3304 hr

The accrued operating time of the motor was 3166.8 hours, and the accrued operating time of the recirculation loop was 3551 hours. PMA performance tests were run at loop temperatures of 1170°F and 495°F following completion of 3028 hours.

b. Test Results

The results of testing in LNL-3 may now be compared with the extensive testing previously accomplished in the NaK simulation loop (NSL) water loop. The projected performance at 495°F and 1170°F NaK (based on NSL tests) is shown in Figures VI-3 and VI-4. The change in PMA performance after 3028 hours of testing is not discernible from the performance at the beginning of the test program. The conclusion reached from this testing is that PMA performance may be reliably and accurately predicted based on good water tests. The test scatter corresponds to the expected instrument variation of ±2% in head, ±2% in capacity, and ±1/2% in power.

By segregating the individual power requirements and losses it is deduced that the NaK eddy current losses were as calculated, and motor rotor hydraulic losses varied as the density change, or, at least, the sum of the losses totaled that previously expected.

The speed torque curve (Figure VI-5), established originally in NSL tests, was confirmed during the LNL-3 testing.

The cavitating performance was confirmed at the heat rejection loop condition (500°F). Figure VI-6 shows that the PMA performance changes were within the acceptable limits down to the rated NPSH.

A series of start tests was performed and the results indicate no increase in starting torque over the last 2500 hours of 1100°F+ operation. The time-temperature log of the PMA (Figure VI-7) indicates the test facility utilization of 92.6%.

c. Hardware Status

Two NaK PMAs for PCS-1 (P/N 093200-13, S/N A-4 and S/N A-6) have been installed in the PCS system. Two PMAs (P/N 096647-11, S/N A-5 and S/N A-2) have been delivered to NASA LeRC. Two additional PMAs were assembled as spares. One PMA, P/N 093200-13, S/N A-5 (LNL-3 unit), was disassembled and is being inspected for engineering evaluation. Two spare stator housing assemblies being fabricated have leaking terminals. New terminals were ordered and fabrication is progressing.

2. Lubricant-Coolant (L/C) Pump-Motor Assembly

a. Testing

During this report period L/C PMA units have operated successfully in the LNL-3, PCS-1 Phase IV, and PCS-1/SL-1 facilities. The PMA (P/N 093580-1, S/N 481501) in LNL-3, was tested in conjunction with the NaK PMA endurance test program. At the close of the test, this L/C PMA had accumulated a total of 4552 hours, including a 1018-hour test at TRW.

The PMA was disassembled for inspection and no visible or measurable signs of wear or deterioration have taken place. Photographs of the impeller, thrust and radial bearing surfaces, and rotor are shown in Figures VI-8, VI-9, and VI-10. A technical memorandum will be written describing the findings in detail.

The PMA (S/N 481504) in PCS-1 Phase IV has operated for a total of 1154 hours with 44 starts. No problems with this unit have been encountered to date. In the PCS-1/SL-1 facility, PMA S/N 481503 has completed 1023 hours with 42 starts with no difficulties encountered. No degradation in performance has been observed in any of these units.

b. Compatibility Tests of ML Insulation and Mix-4P3E Fluid

The test for the ML insulated motor, running submerged in mix-4P3E fluid was concluded after 20,088 hours at 250°F. Examination showed the windings to be in excellent condition. Hi-pot tests at 1000 and 500 v,dc end trim probe tests showed no signs of deterioration. Figure VI-11 shows the appearance of the windings, and also shows the insulation resistance as a function of operating time. These tests show conclusively that no problems exist regarding the compatibility of mix-4P3E and ML electrical insulation for the SNAP-8 system life requirements.

c. Spare Parts

An assortment of PMA subcomponents outstanding against the TRW contract was delivered. Included were four sets of carbon bearings which were inspected, found satisfactory, and will be retained, with the other parts, as spares.

3. Mercury Pump-Motor Assembly

During this report period mercury pump-motor assemblies have operated successfully in the RPL-2 (PCS-1 Phase IV) facility and in the PCS-1/SL-1.

The PMA in PCS-1 Phase IV (P/N 093347-5, S/N A-1) has operated for a total of 794 hours with 58 starts.

The unit in PCS-1/SL-1 (P/N 093340-1, S/N A-1) has completed 756 hours of operation with 36 starts. It is presently remaining in the mothballed SL-1 facility. Plans are to remove this PMA and upgrade it to the 093340-5 configuration for environmental testing.

To date no problems have occurred which would give rise to doubts that the mercury PMA will be able to meet the SNAP-8 life requirements.

a. Test Results

The minor cavitating damage reported in the previous semiannual report (Ref. 27) was evaluated against the time that the pump operated at suction pressures low enough to cause such damage. The total operating time for that particular impeller was 388 hours and investigation revealed that the pump operated for a total of 24 minutes and 48 seconds of apparent cavitating time. This is considered to be sufficient justification for the minor damage observed on the pump impeller.

The PMA in the PCS-1/SL-1 facility is known to have also operated in a cavitating condition for brief periods of time. The test data will, therefore, be reviewed to correlate this with the anticipated damage to the impeller. Plans are to remove this PMA from the facility and disassemble it for inspection in February 1966.

During the total operation of these PMAs, as mentioned above, no noticeable performance degradation has been observed.

b. Operation During PCS-1 Phase IV Step 2 Testing

Operation of the PMA in this facility was the first occasion on which the face-seal liftoff bellows were to be actuated with an auxiliary gas supply following the two bellows failures, as discussed in the previous semiannual report (Ref. 27). Unfortunately, the gas pressure supply intended for the Hg PMA bellows was inadvertently misplumbed. Therefore, the face seals were not actuated, and were in contact with the shaft for all of the 121.21 hours of PMA operation in December. Based on past evaluation, the face seals should be considerably worn.

The only other problem that occurred during these series of tests was that a quantity of mercury (about 7.2 lb) was found in the cryogenic space seal vacuum trap. Conclusions are the valve SSV-14 was closed in error during a start or stop cycle early in the tests and the mercury that leaked into the space seal area during a start cycle was subsequently vaporized and evacuated to the cryogenic trap.

c. Lift-Off Bellows

A proposed new design for the lift-off bellows was received from Metal Bellows Corporation. This includes a controller bellows in the pressure line, with the actuating fluid being maintained in a closed loop between the controller bellows and the actuating bellows. During operation the mercury pump discharge pressure would actuate the controller bellows to a "bottomed out" position. The main advantage of the new design is that a rupture of the actuating bellows would not result in a loss of the pumping fluid (mercury) as has been experienced with the two previous failures. A double failure would have to occur before process fluid is lost from the system.

d. Hardware Status

Assembly of PMA P/N 098100-1, S/N A-1, was completed on 3 December 1965. Scheduled originally for PCS-1 Phase II, this PMA was reassigned to PCS-1 Phase IV for Step 3 testing when redirection of the SNAP-8 program took place. This unit consists of a basic PMA (P/N 093340-5) with the addition of L/C solenoid-actuated isolation valves on inlet and outlet lines, filter screens on the pump suction and discharge lines, and the necessary brackets to support the valves together with an elevated base mount for attaching the brackets.

A PMA (P/N 093340-5, S/N A-3) was completed 20 October 1965 for retention as a PCS spare. Present plans are for the addition of parts to complete this unit to the 098100-1 configuration so that the spare would then be directly interchangeable.

As mentioned previously, PMA P/N 093340-1 is currently installed in PCS-1/SL-1, and plans are to remove it from that facility and, after examination, to rebuild it to the 093340-5 configuration for later environment testing. The principal areas requiring modification are incorporation of motor scavenging slingers, changes to the space-seal heat exchanger fittings, and the addition of triple-vacuum melt bearings.

The PMA (P/N 093347-5, S/N A-1) currently installed in PCS-1 Phase IV has accumulated 794 hours of operation. Two partial disassemblies and examinations have taken place to date after 293 hours and 673 hours. These are referred to in detail in the previous semiannual report (Ref. 27). Present plans are to remove this PMA from the facility at the end of the Phase II test series, and replace it with PMA P/N 098100-1, S/N A-1. The former PMA will then be retained as a spare.

A PMA (P/N 093340-5, S/N A-1) was shipped to LeRC on 11 May 1965.

4. Mercury Pump-Motor Assembly Bearings

Mercury PMA bearings (P/N 095306) delivered to Aerojet during April 1965, were reexamined visually after noting staked and cracked ball retaining lips on the bearing retainer. As a result, nine bearings were returned to the vendor for correction of bearing retainer discrepancies. The ball retainer lips, produced by a cold swaging technique, were cracked, and loose metallic particles easily could have been formed during bearing operation, resulting in bearing failure.

During the week of 20 September, a new design was completed and new retainers were fabricated completely eliminating the cold swaging. The new retainers were inspected and found to be acceptable except for excessive eccentricity on one retainer (over 0.011 in.) and several undersized ball retaining holes, which were later corrected. Examination, however, revealed scratches on some of the balls which were made by the undersized ball retaining holes. Two scratched balls were inspected to determine the depth of the scratches, and they were found to be unacceptable (15×10^{-6} and 30×10^{-6} of an inch depth of scratches, one order of magnitude too large).

All of the balls were inspected by the vendor for scratches and all were found to have various depths of scratches.

The finish of the balls was found to be 0.2 rms (in accordance with the drawing) except for the scratched areas which were on the average 2.0 rms, one order of magnitude too large. New balls will be made as soon as the M-50 bearing steel is received in January 1966. The bearings are scheduled to be completed by the end of March 1966.

C. HEAT EXCHANGERS

The major effort in the development of heat exchangers for the past six months has been in the performance testing and evaluation of components. The scheduled tests of the -1 (tube-in-shell) boiler at Aerojet's Von Karman Center have been completed with the performance evaluation conducted in the Phase I tests in the power conversion system 1 (PCS-1/SL-1) facility. The Phase II tests in the same facility gave performance data for the second SNAP-8 boiler, the tube-in-tube design. These second-phase tests were conducted both with and without the use of rubidium added to the mercury to improve thermal performance during the period when the boiler was conditioning.*

A second boiler of the tube-in-tube design was tested in the rated power loop 2 (RPL-2) facility without the use of additives. Two -1 condensers were evaluated while being subjected to a spectrum of operating parameters, thereby generating a map of condenser performance at design and off-design conditions. The component operating times for the reporting period are shown below.

---

*Conditioning of a boiler denotes the period of operation when its performance improves with time. A boiler whose performance no longer changes with time is termed fully-conditioned.

Component	Part No.	Operating Time Jul-Dec 1965	Operating Time Cumulative
Boiler (Tube-in-Shell)	092952-3	153	226
Boiler (Tube-in-Tube)	097444-5	530	530
Boiler (Tube-in-Tube)	097444-7	120	120
Condenser	092500-1	120	1549
Condenser	093043-3	683	756

The experimental boiling and pressure drop data obtained in scaled single-tube test sections were analyzed. These tests concentrated on determining the heat transfer and two-phase pressure drop characteristics for different mercury-flow-passage geometries at the boiler tube inlet. The conditioning phenomenon was apparent in these tests, and considerable insight into the problem of time-dependent performance was gained.

1. -1 Boiler

a. Boiler Description

The -1 boiler (P/N 092952-3), shown in Figure VI-12 is a combination cross-counter flow, tube-in-shell heat exchanger. The mercury flows through four 60-ft-long tubes coiled on two double-lead helices. A "plug" to restrict flow is placed in the inlet to each of the four parallel flow passages giving a liquid velocity of 0.3 fps. The plug in this restricted-flow section is a solid rod spaced from the inside of the tube by a wire spring forming a spiral flow path for the mercury. This insert continues through the boiler for 10 ft. Downstream of the plug, the vortex flow is maintained by a twisted metal-ribbon insert with a pitch of 7.2 in., which continues for the remainder of the boiler length. The resulting swirl flow separates the high-density liquid from the vapor forcing the liquid droplets against the wall, thus making boiler operation insensitive to gravitational field and increasing heat-transfer rates. The mercury coils are bounded by cylindrical shells that form an annular flow passage for the reactor coolant, NaK-78. The design conditions, materials of fabrication and significant dimensions are shown in Table VI-4.

b. Boiler Conditioning

From the time of the first mercury injection, 26 hours of operation were required before superheated vapor at full mercury flow rate (11,750 lb/hr for the PCS-1/SL-1 test facility) was attained. On subsequent system startups, superheated vapor was produced almost immediately. Figure VI-13 shows the flow rate, temperature and pressure transient for the first mercury injection. These parameters on a subsequent startup are shown in Figure VI-14 for comparison. No significant change was observed in performance after the first 26 hours, based on boiler outlet temperature.

A second parameter that reflects the conditioning history of a boiler of this design is the mercury-side pressure drop. Even though the outlet temperature had reached a steady-state value after 26 hours of operation, the boiler pressure drop continued to increase with operating time. Increase in pressure drop is a reasonable measure of boiler conditioning as changes occur in the heat-transfer process.

One model of boiler conditioning postulates that improved performance results from the erosive action of the mercury on the tube wall surfaces removing oxides and/or other contaminates that add a resistance to the heat transfer. As the boiler performance improves, the local quality increases and evaporation takes place over a continually reducing surface area. This results, then, in an increase in boiler pressure drop. Outlet temperature may only change for a short period of time because, once the vapor approaches the NaK inlet temperature, the superheater portion of the boiler approaches 100% effectiveness and further increases in superheat length will not cause a significant change in outlet temperature, only in pressure drop.

Pressure drop with operating time is shown in Figure VI-15 at constant NaK and mercury-side conditions. These data are consistent with the pressure drop data taken for an identical boiler before it reached fully conditioned performance (Ref. 27). The earlier boiler was not performing at peak efficiency and the pressure drop was 85 psi. When trace amounts of rubidium were added to the mercury in an effort to improve its performance, the boiler pressure drop increased to 140 psi. Based on the earlier tests and the time-dependent change in pressure drop, it was concluded that this boiler was only partially conditioned during the PCS-1/SL-1, Phase I, test series, and that performance evaluation should be tempered with the knowledge that improvement in thermal performance would have occurred with additional operating time.

c. Boiler Performance Evaluation

The boiler is the interface between the nuclear and nonnuclear systems and is subject to the most significant perturbation that occurs in operation: variation in the NaK inlet temperature as the nuclear reactor responds to its temperature control system. The boiler must continually maintain vapor superheat, an acceptable fluid inventory variation, and minimal outlet pressure fluctuations over a 50°F band of NaK inlet temperature. The purpose of the test series performed on this boiler was to evaluate its performance during steady-state variations in the NaK inlet temperature under different NaK and mercury flow rates. The details of this test series have been reported earlier (Ref. 9); the significant performance parameters are shown below.

The basic boiler performance was evaluated at a single point, the rated conditions for the PCS-1/SL-1 test facility:

Primary loop	
NaK flow	46,500 lb/hr
Temperature at boiler inlet	1310°F
Hg loop	
Hg flow	11,750 lb/hr
Condenser inventory	35 lb
HRL	
NaK flow	39,500 lb/hr
Temperature at condenser inlet	486°F

(1) The boiler performance at the rated PCS-1/SL-1 conditions was as follows:

Pressure drop - NaK side	8.5 psi
NaK ΔT	170°F
Pressure drop - Hg side	80-110 psi
Hg temperature at boiler exit	1285°F

Liquid carryover	7-10%
Boiler inventory	86 lb
Pressure oscillation at boiler exit	±12 psi

(2) Varying the primary-loop temperature from 1330 to 1280°F affected the boiler performance as follows:

Pressure drop, NaK side	no significant change
NaK ΔT	decrease 5°F
Pressure drop, Hg side	decrease 5 psi
Hg temperature at the boiler exit	decrease from 1305 to 1250°F
Liquid carryover	(indeterminate)
Boiler inventory	increase by 40 lb
Pressure oscillations at the boiler exit	(indeterminate)

(3) Varying the primary loop flow from 44,000 lb/hr to 49,000 lb/hr affected the boiler performance as follows:

Pressure drop, NaK side	increase by 2 psi
NaK ΔT	decrease 5°F
Pressure drop, Hg side	decrease by 3 psi
Hg temperature at the boiler exit	no change
Liquid carryover	(indeterminate)
Boiler inventory	(indeterminate)
Pressure oscillations at boiler exit	(indeterminate)

(4) Varying the Hg flow from 12,200 to 9400 lb/hr affected the boiler performance as follows:

Pressure drop, NaK side	no change
NaK ΔT	decreased 10°F
Pressure drop, Hg side	decreased 15 psi
Hg temperature at the boiler exit	no change

Liquid carryover	(indeterminate)
Boiler inventory	decreased 20 lb
Pressure oscillation at the boiler exit	(indeterminate)

The conclusions reached based on the PCS-1/SL-1 tests included:

Boiler performance was improving with time during the test series.

The inventory assigned to the boiler showed that boiling was not occurring in the plug insert region of the mercury flow channel.

Outlet conditions were satisfactory for turbine operation.

Liquid carryover was excessive but could be expected to reduce as the boiler improved.

2. Tube-in-Tube (T-T) Boiler

a. Boiler Description

The SNAP-8 tube-in-tube boiler (P/N 097444) shown in Figure VI-16 is a counterflow heat exchanger where the entering subcooled mercury is preheated, evaporated and superheated in a single pass. The mercury flows in seven 30-ft-long tubes that are nested within an outer tube. The NaK is in counterflow in the area between the tubes containing mercury and the outer tube. The entire assembly is coiled to complete the configuration. A "plug" to restrict flow is placed in the inlet of the seven parallel flow passages giving a liquid velocity up to 6.5 fps. The plug in this restricted flow section is a hollow rod spaced from the inside of the tube by either a spiral wire or machined threads, the mercury flowing in a spiral path in the annulus between the plug and tube. The pitch of the spiral flow varies with the boiler configuration, two different geometries having been tested. Downstream of the 5-ft plug, the spiral flow is maintained by a spring insert which rests against the tube inside diameter. The 0.060-in. diameter spring coiled on a 2.5-in. pitch, serves to separate the high density liquid from the vapor as the ribbon turbulator did in the -1 boiler.

As reported earlier (Ref. 27), the T-T design was initiated to develop a boiler that lends itself to diagnostics and incorporates improved design features; i.e., revised plug inserts and turbulator changes.

b. Single-Tube Tests

Tests were conducted in a scaled test loop at Aerojet-General Nucleonics (AGN) to support the T-T boiler design effort. The primary purpose of these single-tube tests was to determine the effects of plug design on boiler performance. The effects of plug design on boiler conditioning have been reported earlier (Refs. 27 and 35). The by-product of these single-tube tests was the generation of heat-transfer and pressure-drop correlations for a boiler tube incorporating a spiral-path plug insert and vortex generator downstream. These correlations were reported in Refs. 36 and 37. A condensation of results follows.

(1) Loop Geometry

The tests were conducted in the corrosion loop (CL-4) facility that was designed to simulate the SNAP-8 dynamic cycle conditions. The corrosion loop layout is shown in Figure VI-17. The operating ranges used for the boiler plug insert experiment were:

NaK Primary Loop	
Boiler inlet temperature	1330°F
NaK flow rate	2050 lb/hr max
Heater power input	35 kw max
Mercury Loop	
Mercury flow	500 lb/hr nominal
Boiler inlet temperature	500°F
Boiler inlet pressure	500 psia max
Boiler outlet pressure	100 psia min

(2) Test Section Description

The mercury boiler was a single-pass counterflow tube-in-shell heat exchanger wound into helix form with a protruding inlet and outlet. Figure VI-18 shows the boiler. The mercury flowed in the tube and the NaK through the annular passage. An inlet plug was inserted into the straight part of the protruding mercury inlet section to increase the liquid-mercury and low-vapor-quality helical velocity. A spiral wire vortex-generator was installed in the coiled mercury tube to promote heat transfer. Spacers were used to center the mercury tube in the annulus. The NaK inlet and outlet are located near the ends of the shell. The boiler configuration and geometry were as follows:

Mean helical coil diameter (in.)	18
Helical shell pitch (in.)	1-3/8
Shell size (in.)	1-1/8 OD x 0.083 wall x 9.959 ID
Tube size (in.)	9/16 OD x 0.0832 wall x 0.397 ID
Vortex wire diameter (in.)	0.049
Vortex wire pitch (in.)	1.5
Coil tube length (ft)	55
Straight tube length (ft)	5
Tube material	9Cr-1Mo
Shell material	316 SS

The boiler was installed in a metal tank assembly and insulated with about 6-1/2 in. of fused alumina bubbles. Six 1/2 in.-thick layers of Fibrefrax insulation was affixed to the outside of the boiler supporting tank assembly.

Instrumentation included twenty-four thermocouples along the length of the boiler outer shell which provided a NaK-side axial temperature profile during operation. These instruments provided the basic data from which heat transfer correlations were determined. Pressure taps were provided at the mercury inlet and outlet and at two intermediate locations along the instrumented plug insert test sections. These pressure readouts provided the basic data for developing empirical two-phase pressure drop correlations.

Figure VI-19 shows the ten test runs conducted and a schematic diagram of the plug insert region of the boiler. Plug inserts were spaced from the inside of the tubes either by wrapping the plug inserts with a spiral wire or by machining a thread on a thick-walled plug. Significant variables investigated were pitch and length of the "tight pitch" preheat section and pitch and length of the "loose-pitch" low vapor quality section of the plug insert.

(3) Test Operation

Tests were conducted under variations in NaK inlet temperature, NaK flow rate and mercury-side outlet pressure. Variations in these parameters change the local quality and heat-transfer rates down the boiler tube. The ranges of test parameters are shown below:

NaK flow rate (W_N)	1700-2300 lb/hr
NaK inlet temperature (T_{NBI})	1345-1260^{o}F
Mercury outlet pressure (P_{HBO})	260-105 psia

(4) Test Data Reduction

The surface temperatures and internal and external pressure taps were used to obtain NaK-side temperature profiles and mercury-side pressure profiles for each data point. A typical profile is shown in Figure VI-20. The data shown on the figure were input data for a computer program which determined the following items for each data point:

- Boiler heat balance
- Plug insert preheat section geometric, dynamic, and thermal parameters
- Plug insert vapor quality section geometric and dynamic parameters
- Plug insert section exit vapor quality
- NaK temperature at liquid-vapor interface
- NaK temperature in terms of vapor quality
- Plug insert vapor quality section local boiling thermal and dynamic parameters

- Unplugged tube vapor quality section local boiling thermal and dynamic parameters
- Plug insert vapor quality section mean thermal parameters
- Unplugged tube vapor quality section mean thermal parameters.

(5) Results and Conclusions

The main conclusions drawn from the test program were as follows:

(a) The introduction of a flow restrictor at the liquid-vapor interface and low-vapor quality regions of the boiler, bringing the inlet liquid velocity to approximately 6 fps, effectively controls the slug flow boiling regime. This approach can possibly overcome difficulties associated with nonwetting or deconditioning of the tube wall surface. This relatively high inlet velocity also results in additional liquid-phase pressure drop leading to an improvement in boiler stability.

(b) Two-phase pressure drop data are adequately correlated by a modified Martinelli parameter.

(c) Boiling heat-transfer rates obtained from a fully conditioned boiler are in fair agreement with proposed semiempirical correlations reported by TRW in the development of the SNAP-2 boiler (Ref. 38).

Two-phase pressure drop in the various regions of the boiler were expressed as:

$$\frac{\Delta P_{TP}}{\Delta P_g} = \phi = \frac{\Delta P_{TP}}{f_v \dfrac{\Delta L}{D_e} \dfrac{(\bar{x}\ G)}{2g_c\ \rho_v}}$$

where

ΔP_{TP} = two-phase pressure drop

ΔP_g = pressure drop if gas phase were flowing alone

f_v = vapor-phase friction factor

D_e = equivalent diameter

ΔL = incremental length

$\bar{x}$ = average quality

G = mass flow per unit area

g_c = gravitational constant

ρ_v = vapor-phase density

The product ϕf_v was correlated in terms of a modified Martinelli parameter λ,

$$\lambda = \left(\frac{\bar{x}\ G\ D_e}{\mu_v}\right)^{0.8} \frac{\mu_v}{\mu_f} \frac{\rho_f}{\rho_v} \frac{\bar{x}}{1-\bar{x}}$$

where

μ_v, μ_f = absolute viscosity of vapor and liquid, respectively

ρ_f = liquid-phase density

Figure VI-21 shows the data obtained in the 6-fps preheat and low-vapor-quality regions. These data were obtained on three variations of plug insert configuration with liquid-phase velocities from 4 to 6.5 fps.

Figure VI-22 shows the data obtained in the intermediate quality region of the boiler tube. This region includes a restricted-flow section with a wire-spring-wrapped plug inserted in the mercury containment tube, again creating a spiral flow path. A "least squares" fit of these data resulted in the following empirical correlation:

$$\phi f_v = 130\ \lambda^{-0.67}$$

Figure VI-23 shows the data obtained in the region of the boiler where no restricted flow section is employed. The data, while scattered, give an adequate correlation for design purposes.

Heat-transfer rates were determined at the initiation of boiling and averaged for each 20% increment of vapor quality. Figure VI-24 shows the heat flux obtained in the region of the liquid-vapor interface. The curve is best fitted by an equation of the form q" = (const) (ΔT_m), implying that single-phase forced-convection heat transfer is the dominant mode, and negligible local boiling is involved. Figure VI-25 shows the curves obtained for each of the five quality increments. A composite curve is shown in Figure VI-26 that indicates the peak heat flux occurring at a vapor quality of $x = 0.50$. This quality "burnout" of 50% was characteristic of all the data generated, independent of plug-insert configuration.

(6) Application to Design

These data were applied in the design of the tube-in-tube boiler. The resulting profiles of the various boiler parameters are shown in Figure VI-27. The velocity profiles are comparable to those employed in the scaled tests to minimize the difficulties with boiler conditioning.

c. PCS-1 Phase I Tube-in-Tube Boiler Tests

(1) Operation Without Rubidium

The first test series on the T-T boiler P/N 097444-5, S/N A-1 was in the PCS-1/SL-1 test facility. Only minimal difficulty with boiler conditioning was anticipated, based on the favorable results obtained with a plug insert with a liquid velocity of 4.5 fps in the scaled single-tube tests at AGN; however, the performance of the boiler on initial startup was poor, as shown by the NaK temperature profile in Figure VI-28. The extended flat portion of the curve is indicative of a region where little heat is transferred. A significant thermal potential exists (difference between NaK temperature and mercury saturation temperature), and the lack of heat transfer is due to the very low mercury film coefficient associated with slug flow boiling. However, this is not static performance as the boiler outlet conditions varied with time. Figures VI-29 and VI-30 show the variation in vapor quality* and outlet

*Note that the quality as determined from the ratio of vapor to liquid flow meters is >100% in some cases. This represents inaccuracy in flow measurement, but the ratio % indicates the trend and time dependence of the data.

temperature with time during the initial operating period of the boiler. Both of these functions continued to increase with time as did the heat-transfer rate in the boiler as shown by the NaK-side temperature profiles. Figure VI-31 shows a NaK temperature profile at approximately rated conditions. The significant feature of the profile is that the heat flux through most of the two-phase region is constant implying an extended length of boiling in the slug-flow regime; i.e., the slope of the NaK temperature profile is constant. This is in contrast to the design curve where the slope peaks out at approximately fifty percent quality reflecting the quality "burnout" obtained in single-tube tests (Figure VI-26). The performance of the boiler following approximately 373 hours of testing is summarized below.

Loop Conditions	
Mercury	
Flow rate	11,750 lb/hr
Exit pressure	279 psia
NaK	
Flow rate	47,500 lb/hr
Inlet temperature	1306°F
Performance Parameter Value	
Terminal temperature difference (NaK inlet to Hg outlet delta-T)	±21°F
Outlet pressure fluctuations	±15 psia (±6%)
Liquid carryover	2 ±5%
Hg pressure drop	30 psi
Excess superheat length	13 ft

Two performance parameters were off-design. The mercury-side pressure drop was considerably lower than the 65 psi design point, and the outlet pressure fluctuations of ±6% were much higher than the ±2% shown at nominal conditions in the single-tube test program.

Based on earlier tests on the tube-in-shell boiler (Ref. 27) where trace amounts of rubidium were added to the mercury to speed the conditioning process, a similar procedure was used in this test series. Anticipated results included a change in the slope of the NaK temperature profile giving increased and nonlinear heat-transfer rates, an increase in boiler pressure drop and excess superheat length, and a decrease in boiler outlet pressure fluctuations.

(2) Operation with Rubidium

Rubidium was incrementally added to the mercury loop over an 8-hour period until the loop inventory reached 0.8 wt% (800 ppm) Rb, based on the amount injected. This addition schedule required approximately 35 lb of a 1% Hg/Rb amalgam. The basis for stopping the addition at 0.8 wt% Rb was that the boiler performance no longer changed with Rb addition.

There was no significant change in boiler performance until the loop concentration reached approximately 200 ppm. At that point, the exit pressure fluctuations decreased to approximately 2% and the temperature profiles showed an increase in superheat length. Addition of rubidium continued until boiler performance did not change. The equilibrium loop concentration was approximately 450 ppm of Rb based on on-line samples obtained from the low-temperature region of the Hg loop.

The equilibrium performance of the boiler after approximately 450 hours of operation is shown in Figure VI-32 where the temperature profile for operation with Rb is compared with the profile taken earlier in the test before Rb injection. These profiles show an average heat flux of 66,000 Btu/hr-ft^2 in the boiling and preheat regions of the boiler before Rb addition, and 100,000 Btu/hr-ft^2 after Rb addition. Other performance parameters are compared in Table VI-5.

Both the outlet pressure fluctuations and the temperature profiles approached design values, but the mercury-side pressure drop remained less than design. Furthermore, the pressure drop showed only slight dependency on mercury flow rate and NaK-side conditions contrary to the design analysis which predicted a 30% variation in boiler pressure drop over the $50^{o}F$ range of NaK inlet temperature, 1305 $\pm 25^{o}F$. A complete performance map was obtained on the boiler to determine its response to variations in system parameters.

(3) Performance Map with Rb

The parameter which is directly affected by all variations in independent variables is the temperature at the liquid-vapor interface which is termed the pinch-point temperature difference:

$$\Delta T_P = T_{NINT} - T_{HINT} \tag{1}$$

The NaK temperature at the interface, T_{NINT} is determined from a heat balance around the preheater:

$$T_{NINT} = T_{NBO} + \frac{C_{PH} W_H (T_{HINT} - T_{HBI})}{C_{PN} W_N} \tag{2}$$

where

T_{NBO} = Boiler outlet temperature

C_{PH}, C_{PN} = Specific heat of liquid Hg and NaK, respectively

W_H, W_N = Flow rate of Hg and NaK, respectively

T_{HINT} = Saturation temperature of mercury at the interface

The mercury temperature at the interface is the saturation temperature at the interface pressure. The interface pressure was approximated by the readout of the pressure tap located at the end of the tight-pitch section of the plug insert for these tests. Combining Equations (1) and (2),

$$\Delta T_P = T_{NBO} + \frac{C_{PH}}{C_{PN}} \frac{W_H}{W_N} (T_{HINT} - T_{HBI}) - T_{HINT} \tag{3}$$

where

$T_{HINT} = f\ (P_{HINT})$

The variation of boiler pressure drop, terminal temperature difference and excess superheat length with pinch-point temperature difference are shown in Figures VI-33, VI-34, and VI-35. Two factors are apparent, the pinch-point temperature difference is an adequate correlating parameter for this particular boiler and the Hg-side pressure drop shows surprisingly little sensitivity to either pinch-point temperature difference or flow rate.

An evaluation of the pressure drop data added little in resolving the discrepancy between the design and test results. One explanation is that boiling is not occurring in the tight-pitch section of the plug insert even with the addition of Rb. A second explanation is that the boiler tubes are not performing uniformly, caused either by a nonuniform NaK flow distribution or by a variation in tolerances from tube-to-tube giving variations in plug-insert clearance and hence pressure drop. Although the question has not been resolved, considerable insight into the problem was gained through an analysis performed to investigate the effects of radial clearance on plug-insert pressure drop. Figure VI-36 shows the effect of radial clearance and eccentricity on pressure drop occurring in the plug insert. Also shown is the ratio of flow over the lands of the plug to flow down the spiral channel. Appreciable deviation from the 0.000-0.002 in. design clearance could lead to a significant reduction of pressure drop as shown.

The tests on the PCS-1 boiler showed that conditioning remains a problem, even with the plug insert modified from that used in the tube-in-shell boiler (increase in liquid velocity from 0.30 to 4.5 fps). The tests again verified that Rb is an effective additive in conditioning the boiler. Finally, the tube-in-tube boiler was shown to adequately meet SNAP-8 system requirements with ample margin in pressure drop and heat-transfer surface area. Outlet pressure oscillations and liquid entrainment, while present, are minimal and do not preclude attainment of the 35 kw system power requirement.

d. PCS-1 Phase IV Step 1 (RPL-2) Tube-in-Tube Boiler Tests

The purpose of the tests performed in this facility was to obtain an additional data point in the course of boiler development. The specific test conditions were again designed to determine the steady-state response of the boiler to variations in parameters.

The independent system variables, as far as the boiler is concerned, include mercury flow rate, mercury exit pressure, mercury inlet temperature, NaK flow rate, and NaK inlet temperature. The responses of the boiler to these parameters are the outlet mercury conditions (temperature, carryover, pressure oscillations), mercury inventory requirements, mercury inlet pressure, NaK outlet temperature, and NaK-side pressure drop.

The primary objective of this test series was to obtain a performance map of the boiler with variations in NaK and mercury flow rates, NaK inlet temperature and boiler outlet pressure. The specific test conditions are shown in Table VI-6.

A secondary objective was to obtain a set of data from which off-design pressure drop information could be obtained. The test conditions for these points are shown in Table VI-7.

The boiler (P/N 097444-7, S/NA-2) initially contained a set of plug inserts which gave a 6.5 fps liquid velocity in the 24-in.-long tight-pitch section of the plug. On initial startup the boiler was producing superheated vapor at an approximate mercury flow rate of 1500 lb/hr. However, further opening of the mercury throttle valve gave no increase in flow rate. Analysis of the data indicated that a restriction was occurring at the boiler inlet.

Several approaches to the problem showed that the most likely cause for the excessive pressure drop was that boiling was occurring in the tight-pitch section of the plug insert to a very high quality even at low flow rates.

Testing was resumed to confirm the repeatability of the high pressure drop and, then, to deliberately flood the offending tight-pitch section of the boiler with liquid thereby reducing the pressure drop. The repeatability of the high pressure drop was confirmed. However, it was impossible to flood the tight-pitch section of the plug without flooding the entire boiler. This was caused by poor (deconditioned) performance downstream of the plug-insert section. The resulting negligible pressure drop between the plug-insert end point and boiler exit, even at mercury flow rates to 11,000 lb/hr, permitted the boiler to fill easily with mercury once the interface was moved out of the plug insert region. It was impossible to hold a steady-state condition in which the boiler pressure drop could be evaluated exclusive of the pressure drop occurring in the tight-pitch section; but, sufficient data were obtained to demonstrate conclusively that the plugs were responsible for the excessive pressure drop.

A set of plug inserts was modified to facilitate installation and installed in the boiler. These plug inserts gave a 4.5 fps liquid velocity with their 3/8-in. pitch x 12-in. long tight-pitch section. The boiler plug geometry was comparable to the unit tested in PCS-1 Phase I (described in Section VI,C,1 of this report).

(1) Conditioning

Following several short startups, which were terminated because of facility problems, the boiler was operated for 24 hours during which time it reached a conditioned state. The total operating time before the boiler was considered conditioned (including operation with the high-velocity plug inserts) was 42 hours. The detailed conditioning history is presented in Ref. 4, where the parameter plots for the conditioning period are shown.

The boiler NaK temperature profile for the conditioned period is shown in Figure VI-37. During the conditioning period the excess superheat length increased from essentially zero to 12 ft during which time the outlet quality increased from 75 to 100% as indicated by a heat balance. The mercury outlet temperature increased from saturation to over 200°F superheat as the terminal temperature difference (difference between NaK inlet and mercury outlet temperatures) decreased to 20°F.

(2) NaK-Side Profiles

Temperature profiles were determined for each data point in the test. A typical profile is shown in Figure VI-38. Shell-side instrumentation included two axial temperature profiles, one at the top of the shell and one at the bottom. Therefore, two profiles are shown. Ideally, the two curves should coincide. However, the plots all show two distinct curves that diverge from the region where vaporization is complete.

Several explanations have been considered for this phenomenon, none of which have been discarded to date. A maldistribution of NaK, caused by improper shell-side baffles would account for the profile where excess NaK passes along the upper tubes and insufficient NaK passes along the lower tubes. An alternative cause is that the tubes are not uniform in performance, the upper tubes carrying a smaller portion of the mercury and giving a lower NaK-side temperature drop, with the lower tubes carrying a higher-than-proportionate share of the mercury and giving the large NaK-side temperature drop. In either case, the resulting NaK-side profiles would be nonuniform as shown. The discrepancy in profiles is still under investigation and has not yet been resolved.

The difficulty in interpreting the slope of the NaK profile because of the divergence of the two curves generated in test has precluded a detailed analysis of heat transfer in the various quality regions of the boiler. However, the fact that the profiles converge at the region where vaporization is completed has permitted an evaluation of overall boiler performance.

(3) Pinch-Point Temperature Difference

The pinch-point temperature difference was determined for each data point using Equation (3) with the mercury pressure at the interface estimated from the inlet pressure and calculated liquid-phase pressure drop.

(4) Boiler Pressure Drop

Boiler pressure drop was correlated with pinch-point temperature difference and mercury flow rate as shown in Figure VI-39. The resulting analytical expression

$$\Delta P_H = \left(\frac{W_H}{12,800}\right)^{1.8} 77 + 0.37\ \Delta T_P \tag{4}$$

is based primarily on the data at a flow rate of 12,000 lb/hr. It shows fair agreement at other flow rates, but should be applied with caution at a flow rate greater than 12,000 lb/hr or less than 6000 lb/hr.

The total boiler pressure drop at 11,500 lb/hr in the range of pinch-point temperature difference for 33 to 78°F is 80 to 95 psi. This compares with the design analysis (Ref. 39) of 55 to 79 psi at this flow rate. The difference between the design and test results, while significant, does not preclude the use of this boiler in a system. The discrepancy is most likely caused by a greater pressure drop in the plug insert region than anticipated, reflecting the uncertainty in calculating two-phase pressure drop in a relatively complex geometry under nonadiabatic, variable-flow-regime environment. The agreement between test and design is considered adequate under the circumstances.

The fact that these data show a considerably greater pressure drop than the tests on a boiler of similar design tested in PCS-1/Phase I is disconcerting. The variation in performance between the two boilers is significant and reflects difficulty inherent in accurately predicting boiler performance. Again, the reason for the disparity in performance has not been resolved. But, the effects of radial clearance on plug section pressure drop has been demonstrated analytically (Figure VI-36 and Section VI,C,1,c of this report) and could account for much of the disparity. Unfortunately, this boiler was not instrumented with internal pressure taps and pressure distribution on the mercury-side was not determinable.

(5) Terminal Temperature Difference

Terminal temperature difference, the difference between the NaK and mercury outlet temperatures, was correlated with pinch-point temperature difference as shown in Figure VI-40. The data show a distinct grouping at approximately 20°F at a pinch-point temperature difference greater than 40°F with a slight increase at pinch points from 20-40°F. Over the range of SNAP-8 operating conditions ($30 \leq \Delta T_P \leq 80$), the terminal temperature difference is always less than the design point of 30°F which will assure a minimum inlet temperature of 1250°F to the turbine even at the minimum NaK inlet temperature to the boiler of 1280°F.

If the superheater of the boiler is considered a separate heat exchanger, its effectiveness is given by

$$\epsilon = \frac{T_{HBO} - T_{HS}}{T_{NBI} - T_{HS}} \tag{5}$$

At SNAP-8 design conditions, the average saturation temperature at the boiler exit is approximately 1065°F. Using a terminal temperature difference of 20°F at the nominal NaK inlet temperature of 1305°F,

$$\epsilon = \frac{1285 - 1065}{1305 - 1065} = \frac{220}{240} = 0.92$$

Recognizing the qualitative significance of considering the superheater a separate heat exchanger, the 92% nominal effectiveness still is indicative of the favorable performance of the boiler.

(6) Outlet Pressure Stability

The boiler outlet pressure strip chart data were reviewed for all data points taken during the performance mapping. A typical strip chart record is shown in Figure VI-41. The frequency for all data averaged approximately 0.25 cps. The anticipated frequency was 0.29 cps obtained from the calculated "stay-time" through the boiler of 3.5 sec.

The magnitude of pressure oscillations was averaged for each data point. The data were nondimensionalized by taking the ratio of outlet pressure oscillation magnitude to outlet pressure. The resulting expression for deviation in outlet pressure was plotted with pinch-point temperature difference as shown in Figure VI-42. The data were correlated with an equation

$$\frac{\sigma_{P_{HBO}}}{P_{HBO}} = \pm \left[5.50 - \left(\frac{\Delta T_P + 20}{2.74} \right)^{0.424} \right] \% \qquad (6)$$

Over the nominal SNAP-8 operating range ($30 \leq \Delta T_P \leq 80$), the data show a deviation in outlet pressure from ± 2.1 to $\pm 0.9\%$.

While adequate, the system must pay a penalty for this instability in boiler performance and a reduction in magnitude of oscillation is desirable. Two of the potential contributors to this instability are flow regime transition and negative derivative of pressure drop with respect to flow rate. The former is caused by the development of a slug flow regime as the fluid makes the transition from all liquid to fully-developed two-phase vortex flow. The magnitude of oscillation can be reduced by decreasing the channel size and length over which the transition takes place. Future work in the redesign of plug inserts will be along these lines. A negative derivative of pressure drop with respect to flow rate can be eliminated by increasing the liquid-phase pressure drop in each channel. A restriction at each channel entrance is also being considered for future boilers.

(7) Mercury Inventory

The mercury inventory required was determined for each boiler test point. The startup of the loop prior to the testing of the boiler was conducted to assure a complete filling of the lines between the condenser and boiler prior to startup. This was accomplished by prefilling the condenser, opening the flow-control valve until the boiler outlet temperature showed a significant increase, closing the valve until the condenser level had steadied out, and, then, starting up.

The steady-state condenser level was the base-line for the boiler inventory determination. The inventory lost from the condenser from this zero reference was assigned to the boiler and is reflected in the data. The condenser inventory was determined from the condenser inlet and exit pressures neglecting any pressure drop in the condensing process.

The results were plotted as a function of pinch-point temperature difference as shown in Figure VI-43. The data were correlated with the equation shown below.

$$I_B = 60 - \left(\frac{\Delta T_P + 15}{7.09 \times 10^{-7}}\right)^{0.204}, \text{ lb} \tag{7}$$

The curve shows that, over the SNAP-8 operating range ($30 \leq \Delta T_P \leq 80$), the inventory shift is 7 lb with a maximum inventory of 20.5 lb. The inventory calculated for this boiler was 25 lb, which is in fair agreement with the test data.

(8) Liquid Mercury Carryover

The values for liquid carryover are shown in Figure VI-44 for the data points devoted to the off-design pressure drop determination. Values of exit quality, as determined by the ratio of vapor-to-liquid flow rates, were plotted as functions of liquid flow rate.

The plotted data show the problem in determining quality that is related to carryover as shown below:

$$Y \equiv 1 - X, \% \tag{8}$$

The large scatter in data results from the relatively large errors in flow measurement. The four curves based on the ratio of flow rates are determined from each permutation of flow rate ratio with two redundant liquid flow meters and two redundant vapor flow meters.

The only characteristic common to all methods is that there seems to be no dependency of exit quality with flow rate. The expected shape of the curves is a divergence (concave downward) from the horizontal as flow rate increases; i,e., increasing carryover (decreasing quality) with flow rate. The absence of such a trend is encouraging, but there are insufficient data available to generalize the results.

Post-test calibrations are planned in an effort to resolve this discrepancy but, even with accurately calibrated flow meters, the expected individual flow rate error of $\pm 5\%$ results in an error in quality of approximately $\pm 7\%$. A considerable amount of data will be required to run a statistical determination of carryover with reasonable confidence levels. For example, carryover on the tube-in-shell boiler (Ref. 27) was determined statistically with over 600 data points used in the analysis.

(9) Boiler Startup

Two simulated system startups were conducted to determine if the boiler could adequately respond to relatively rapid changes in independent variables. The two startups differed by the procedure used to increase the NaK flow rate. In the first test, the NaK flow rate was raised from 22,500 to 45,000 lb/hr (approximately 50 to 100% rated) while the mercury flow was at the end of its first ramp (4400 lb/hr). In the second test, the NaK flow was increased simultaneously with the mercury flow rate more closely simulating the transition from inverter to TAA power that occurs during the startup of the SNAP-8 system.

Plots of the key system parameters during the startup simulations are shown in Figure VI-45 through VI-48. Figures VI-45 and VI-46 show the startup conducted on 10 December 1965 and prior to the performance map, while Figures VI-47 and VI-48 show the second startup on 12 December 1965, which followed the completion of boiler testing.

In both startups, the system response was satisfactory and a successful startup of the boiler occurred. The figures show the time delays in the boiler as boiler outlet temperature and pressure respond to change in mercury flow rate.

The first startup showed that the inventory shift associated with mercury injection was a maximum of 30 lb with a steady-state value of 17 lb. The second startup did not show this overshoot, but gave a continual increase in inventory to a maximum of 18 lb. The reason for the overshoot and recovery of inventory on the first startup is uncertain, but may have been associated with a high temperature rise on the HRL cooler when the louver control on the fin-fan cooler malfunctioned. In any event, the shift in inventory is not large enough to significantly affect boiler startup.

Both startups showed an oscillation in boiler pressure drop. This should not be confused with boiler outlet pressure oscillation as shown by the relatively smooth curve of P-202. The oscillations in pressure drop are considered "natural" fluctuations in the system as the boiler responds to changes in flow rate and NaK inlet temperature imposed by the flow control valve and NaK heater control system.

(10) Conclusions from RPL-2 Testing

The performance map and auxiliary tests performed on the tube-in-tube boiler have shown that it can be used satisfactorily in the SNAP-8 system. The specific performance parameter variations under SNAP-8 operating conditions ($30 \leq \Delta T_P \leq 80$) are shown below:

	Pinch-Point ΔT	
	30	80
Pressure drop (psi)	80	95
Inventory (lb)	23	20
Pressure oscillation		
Frequency (cps)	0.25	0.25
Magnitude (% P_{HBO})	2.1	0.9
Terminal temperature difference (^{o}F)	20	20

Some improvements in design have been suggested by these tests including:

(a) A method or design change to assure immediate startup is required. Forty-two hours were required to condition this boiler.

(b) Elimination or reduction, or both, in potential NaK-side mal-distributed flow through improved baffles is needed.

(c) Reduction in pressure-drop oscillation by increasing liquid phase pressure drop and compressing length required for flow regime transition from all-liquid to vortex flow is desirable.

3. Evaluation of Boiler Development Status

Two boilers have been designed and tested during the course of the SNAP-8 program, with mixed results. Operation of both boilers was hampered with a startup conditioning problem apparently related to the interaction of the mercury on the containment-material surface. Additional work to resolve this problem is required.

Rubidium added to the mercury in trace amounts (less than 1000 ppm) has been shown to be an effective means of accelerating the conditioning process with both boiler designs. Potential side-effects associated with the interaction between Rb and surface oxides, wherein solid precipitation is formed which can locally accumulate, have precluded its general use in the SNAP-8 system. However, additions of rubidium to the mercury remain a potential solution to the boiler conditioning problem.

A comparison of the two boilers tested is shown in Table VI-8. The current tube-in-tube design is considered superior both in fabricability and performance. Of significance, is the adequacy of both boilers to meet design thermal requirements.

In the case of the tube-in-tube boiler, the pinch-point temperature difference has been shown to be the most significant correlating parameter in determining performance. Pressure drop, inventory, outlet temperature and boiler stability were correlated with pinch-point, clearly demonstrating the significance of the minimum available thermal potential, which occurs at the liquid-vapor interface in this pure counterflow design. The importance of maintaining reasonable minimum pinch-point temperature differences has led to consideration of alternative NaK flow schemes, which provide counterflow through the bulk of the boiler with parallel flow in the region of the liquid-vapor interface.

The performance analysis has shown four areas where design modifications can offer improvement.

a. Inconsistent Performance from Unit to Unit

One disconcerting result of the boiler development program has been the variation in performance from unit to unit. The mercury-side pressure drop has been the primary example where considerable variation was encountered even in boilers that were considered fully conditioned. Manufacturing tolerances have been shown analytically to play an important part in determining performance in the plug insert region, and should be improved either through new fabrication processes or by changes in configuration.

b. Shell-Side Flow Distribution

While nonuniformity of shell-side flow is only suspected, revised baffling to assure uniformity should be included in any design modification. Isothermal flow tests to determine flow distribution should be included.

c. Reduction of Liquid Carryover and Boiler Outlet Pressure Fluctuations

Both liquid entrainment and outlet pressure fluctuations were reduced in going from the tube-in-shell to the tube-in-tube design. While the results from the initial tests imply acceptably low values of outlet pressure fluctuation and entrainment, the SNAP-8 system pays a penalty for even the current levels; and design modifications are being considered to reduce pressure instability and entrainment even further.

4. -1 Condenser

The two series of tests on the -1 condenser have resulted in an adequate evaluation of its performance. Testing in the PCS-1/SL-1 facility was limited to low values of NaK inlet temperature to the condenser, while the tests in the RPL-2 facility were conducted at the design levels. Therefore, tests in the RPL-2 facility are stressed in this report as they closely follow the intended range of variables giving a more complete map of performance.

a. Condenser Description

The -1 condenser, shown in Figure VI-49, is a counterflow tube-in-shell heat exchanger with fixed tube sheets. The 73 tapered tubes contain the condensing mercury with the coolant contained in the tapered shell. The shell-side coolant is the eutectic mixture of sodium and potassium (NaK) that flows through the condenser as part of the heat-rejection system.

Tapered tubes are used to maintain vapor velocity through the condenser length providing a continual movement of condensate to the liquid vapor interface by the vapor drag on the condensing droplets in very low gravity operation. The condenser design parameters are shown in Table VI-9.

The operational requirements of the condenser in the SNAP-8 system are threefold:

(1) Provide a back pressure (condensing pressure) on the turbine commensurate with system power requirements.

(2) Provide subcooling to assure adequate NPSH to the mercury pump during operation in very low gravity.

(3) Provide mercury inventory storage capacity to make up for leakage from the Hg PMA and TAA seals to space.

This test series on the -1 condenser was designed to verify the capability of the component to meet these requirements with parameter variations simulating operation in a full SNAP-8 system.

Tests were conducted with a desuperheater-sonic nozzle combination simulating operation with the TAA. Coolant flow to the desuperheater was varied to obtain the appropriate vapor quality to the condenser.

Tests were performed at two NaK inlet temperature simulating steady-state condenser operation during periods when the radiator is operating in either sun or shade for the most severe mission considered for the SNAP-8 system, a Venus orbit.

Two mercury flow rates were tested, bracketing the design and current system requirements.

The details of these condenser tests are contained in the Condenser Test Plan and Condenser Test Specification (Refs. 40 and 3). The test series has been reported in detail in Ref. 41.

b. Test Objectives

The independent variables, as far as the condenser is concerned, that affect its performance include mercury inlet quality, mercury flow rate, mercury inventory, NaK flow rate and NaK inlet temperature. The main responses of the condenser to perturbations in these variables are changes in the pressure at which condensation takes place, the outlet temperature of both fluids, and the pressure drop of both fluids.

The objective of this test series was to obtain a performance map of the condenser with variations in mercury flow rate, mercury inventory, NaK flow rate, and NaK inlet temperature. Mercury inlet quality was not varied and mercury-side pressure drop was not accurately obtained because of the vertical orientation of the unit.

The conditions selected for the test program are shown in Table VI-10. The tests were performed in increments with an initially fixed mercury inventory, NaK inlet temperature, and mercury flow rate. The NaK flow rate was adjusted to give the desired mercury-side inlet pressure. Subsequent test points in each increment were obtained by varying only one parameter, the mercury inventory; all other controls were left alone; i.e., if the mercury flow rate changed as a result of changing the inventory in the condenser, this flow was not adjusted and the change became part of the response of the condenser.

Data obtained directly from this test series included:

A determination of the required NaK flow rate to obtain a desired condenser inlet pressure.

With the NaK flow rate established, determination of the variation of inlet pressure, NaK outlet temperature, and mercury outlet temperature with mercury inventory.

Additional information obtained during the test was used to compute the overall heat-transfer coefficient in the condenser to be used in any design modifications.

c. Test Data Analysis

(1) Temperature Profiles

The performance of the condenser, like that of the boiler, can be evaluated with the aid of a shell-side temperature profile.

Profiles were plotted for each data point to confirm the location of the liquid-vapor interface and indicate the region within the condenser where the bulk of the heat is transferred. Noting that the local heat flux is proportional to the slope of the temperature profile, an insight into the condensing process is gained by considering variation in thermal performance with changes in independent variables.

A typical profile is shown in Figure VI-50. The location of the interface is pronounced as noted by the sharp break in the profile. Also apparent is the region where most of the latent heat is removed, the steeply ascending region of the profile.

(2) Required NaK Flow Rate

The data for the first test condition of each increment showing the required NaK flow rate as a function of mercury flow rate and NaK inlet temperature are shown in Figure VI-51.

At a mercury flow rate of 12,000 lb/hr and a NaK inlet temperature of 500°F, the predicted NaK flow rate was 42,500 lb/hr to give a condensing pressure of 16.5 psia compared to a flow of 39,000 lb/hr for this test. The difference is ascribed to a higher overall heat-transfer coefficient achieved in test compared with the design value of 960 Btu/hr-ft^2-°F.

The data from this test series are shown on Figure VI-52 with the predicted required NaK flow rates from Ref. 42, based on data from the MECA tests at LeRC. The tested and predicted flow rate requirements are in fair agreement.

(3) Variation in Condensing Pressure with Inventory

The effect of available condenser surface area on condensing pressure (inlet pressure) is shown in Figure VI-52. The available surface area is varied by changing the amount of liquid within the condenser tubes during the test.

The data show the expected trend of a relatively flat portion at long condensing lengths with a distinct rise in condensing pressure as more and more liquid is added. The essentially flat portion of the curves with condensing lengths greater than 35 inches implies an excess surface area is available. However, the condenser does require some margin to make up for seal leakage during operation.

(4) NaK Outlet Temperature

The data on NaK outlet temperatures have been combined with the mercury inlet temperature data and plotted as the terminal temperature difference, ΔT_T as a function of condensing length in Figure VI-53.

The shape of this curve is as expected, showing increasing terminal temperature differences as the condenser fills with liquid. However, analysis showed that the curve should have been displaced to the left. The predicted curve is shown in Figure VI-54 which was based on the single-tube MECA test data (Ref. 42).

The reason for this discrepancy is uncertain and is still being investigated. In any event, the discrepancy is not serious to performance as the condenser can still fulfill its system requirements, only with less margin than anticipated based on the single-tube tests.

(5) Mercury Outlet Temperature

The effectiveness of the subcooler is nearly 100%. The temperature difference between the mercury exit and NaK inlet averaged 0.5°F with a spread in data from -1 to +2°F.

This was expected because of the high local coefficients associated with both the NaK and mercury sides of the subcooler. With subcooler lengths greater than 3 in., the design analysis predicted a subcooler effectiveness of 99%.

(6) Heat Balance

The mercury inlet quality to the condenser was determined by a heat balance around both the desuperheater and the condenser.

Condenser heat balance:

$$X_C = \frac{1}{W_H \lambda} \left[W_N C_{PN} (T_{NCO} - T_{NCI}) - W_H C_{PH} (T_{HCI} - T_{HCO}) \right] \qquad (9)$$

Desuperheater heat balance:

$$X_{DS} = 1 - \frac{1}{\lambda\, W_H}\left[W_{DS}\, C_{PN}\,(T_{NDSO} - T_{NDSI}) - C_{PHV}\, W_H\,(T_{HDSI} - T_{HDSO})\right] \quad (10)$$

where

X_{DS}, X_C = Quality entering condenser

W_H, W_N, W_{DS} = Flow rate of mercury, NaK in condenser and NaK in desuperheater, respectively, lb/hr

C_{PN}, C_{PH}, C_{PHV} = Specific heat of NaK, liquid Hg and Hg vapor, respectively, Btu/lb-^oF

λ = Latent heat of vaporization, Btu/lb

T_{NCO}, T_{NDSO} = NaK temperature of the condenser and desuperheater, respectively, ^oF

T_{NCI}, T_{NDSI} = NaK temperature into the condenser and desuperheater, respectively, ^oF

T_{HCI}, T_{HDSI} = Hg temperature into the condenser and desuperheater, respectively, ^oF

T_{HCO}, T_{HDSO} = Hg temperature out of the condenser and desuperheater, respectively, ^oF

An error analysis of the heat balances showed that both methods could give an error of $\pm 8.1\%$. However, the average difference in the mercury inlet quality between the two heat balances was 2.4%, which is considered adequate for the calculation of overall heat-transfer coefficients.

(7) Overall Heat-Transfer Coefficient

The overall heat transfer coefficient is calculated from the data of flow rates, condensing length, temperatures and inlet quality.

$$U = \frac{Q_C}{A_C\,(LMTD)}\ \text{Btu/hr-ft}^2\text{-}^oF \quad (11)$$

where

Q_C = Heat transfer in condenser, Btu/hr

U = Overall coefficient of heat transfer, Btu/hr-ft^2-$^\circ$F

The condensing area, A_C, is found from the condensing length, L_C:

$$A_C = 8.4 \left(\frac{L_C}{12}\right) - 0.73 \left(\frac{L_C}{12}\right)^2 \tag{12}$$

While the log mean temperature difference is given by:

$$LMTD = \frac{(T_{HCI} - T_{NINT}) - (T_{HCI} - T_{NCO})}{\log_e \dfrac{T_{HCI} - T_{NINT}}{T_{HCI} - T_{NCO}}} \tag{13}$$

where

T_{HCI} = Mercury inlet temperature

T_{NINT} = NaK temperature at the liquid-vapor interface

T_{NCO} = NaK outlet temperature

The NaK temperature at the liquid-vapor interface is determined from a heat balance around the condenser-subcooler.

$$T_{NINT} = T_{NCI} + (T_{NCO} - T_{NCI}) \frac{C_{PH} (T_{HCI} - T_{HCO})}{X_C \lambda} \tag{14}$$

Statistical analysis of data showed that the mean value of overall coefficient was 1090 Btu/hr-ft^2-$^\circ$F with a standard deviation of 138 (12.7%). This value is very close to the calculated error, 14.5%, based on expected deviations in the measurements.

This value of overall coefficient is less than other condensers tested but represents an adequate margin over the design. The various condensers tested and their value of overall coefficient are shown tabulated below:

Condenser - Description	Overall Coefficient Btu/hr-ft^2-$^\circ$F	Standard Deviation
Single tube - MECA	1900	Unknown
-1 Model - Design Analysis	960	-
-1 Model - PCS-1 Tests	1485	323
-1 Model - RPL-2 Tests	1089	138
-1 Model - All Tests	1260	225

The variation in overall coefficient in the two -1 condensers tested is shown above. However, the variation may not be real as the standard deviation of both sets of data overlap. In any event, there is a high probability that the value of overall coefficient is well above the design value of 960 Btu/hr-ft^2-$^\circ$F.

d. Conclusions

The condenser can meet its system requirements as shown below:

(1) NaK flow rate to reach 16.5 psia at 40 in. condensing length, 500°F NaK inlet temperature, 11,000 lb/hr mercury flow rate, 96% quality.

Required = 39,500 lb/hr
Tested = 36,500 lb/hr

(2) Mercury inventory storage capability at conditions noted above:

Required = 10 in.
Tested = 18 in.

(3) Adequate subcooling at minimum subcooling length (45 in. condensing length) as reflected by difference between NaK inlet and mercury outlet temperatures.

Required = $5^{o}F$

Tested = $2^{o}F$ (max)

The calculated values of overall coefficient were lower for this series of tests than either the earlier tests in PCS-1 on a condenser of a similar design or the single-tube tests conducted under the MECA project. However, the mean value of 1090 Btu/hr-ft^{2}-^{o}F exceeds the design value of 960 Btu/hr-ft^{2}-^{o}F by a 13% margin.

Two factors remain to be verified in the design of this condenser; its multitube stability performance in a low-gravity environment, and its mercury-side pressure drop. This information will be determined in multitube horizontal tests later in the course of SNAP-8 development.

5. Auxiliary Start Loop Heat Exchanger

An auxiliary start loop heat exchanger incorporating the bypass flow arrangement recommended in the last report (Ref. 27) has been designed (P/N 093607-11) and fabricated. Tests will be completed during PCS-1 Phase IV Step 3 tests in conjunction with system startup development.

D. VALVES AND CONTROLS

1. Temperature Control Valve (TCV)

Because of the significant deviations from the desired flow phenomenon (Figure VI-55), and the mechanical sticking problem encountered during temperature calibration, it was decided that the Roylyn temperature control valves would not be used to support systems tests. The Roylyn S/N 002 valve was discussed in the previous semiannual report (Ref. 27). The total performance curve for the Roylyn S/N 001 valve is shown on Figure VI-55. Valve leakage in the full-closed position was 910 lb/hr. The design requirement was 0.22 lb/hr. The full-open pressure drop was 2.6 psi compared to the design value of 0.1 psi. During control chamber calibration, the butterfly consistently stuck in the full-open position and would not close with the valve design chamber pressure of 43 psia. However, it would move freely to the full-open position from the start-of-opening position.

An order for replacement valves was placed with the Vinson Manufacturing Co., Van Nuys, California on 25 July 1965. The valve configuration consists of a shear plate with a shaped orifice that exposes a venturi section, thus modulating the flow. When the valve is wide open, the flow vs pressure-drop characteristic is that of an unrestricted venturi. Movement of the shear plate is governed through a bellows linkage by thermal expansion of trapped NaK in a control chamber. The temperature of the NaK in the control chamber is always essentially the same as the process fluid temperature. Therefore, the temperature of the process fluid (HRL condenser outlet temperature) determines the valve opening. Details of the valve assembly are shown on Figure VI-56.

After the valves are delivered, the control chambers will be charged with NaK and a temperature vs valve opening calibration conducted. NaK control chamber filling and calibration instructions were completed and calibration-fixture design was initiated.

2. Condenser Bypass Valve (CBV)

The condenser bypass valve was delivered on 3 December 1965. A photograph is shown on Figure VI-57. The results of final flow checks conducted by the vendor are shown on Figure VI-58, which is a plot based on valve position.

Support activities for temperature calibration were completed; calibration instructions were issued, calibration fixtures were fabricated, and a NaK fill loop assembled.

After the NaK control chamber is filled, a temperature vs valve opening calibration will be conducted. Deviation from design values will result in a change in slope of the actual performance curve shown on Figure VI-58.

3. Double-Solenoid Latch Valves (P/N V-54600-06 and P/N V-54600-04)

Evaluation of these valves based on performance in RPL-2, SL-1, PCS-1 Phase IV Step 1, and individual checkout tests was completed.

No operational problems were encountered during RPL-2 testing. The V-54600-04 valves were used for TAA L/C inlet and outlet shutoff valves and the Hg PMA L/C outlet valve. Uses in SL-1 included the mercury filter bypass valve and the Hg PMA L/C inlet and outlet valves. Sporadic malfunctions occurred during loop operation. The mercury filter bypass valve would not open when the loop temperature was above 300°F, and the Hg PMA L/C valves malfunctioned after successfully actuating 38 and 19 consecutive times, respectively. In all instances, the valves operated normally during post-test investigations at room temperature. It was concluded that the malfunctions were a result of local environmental conditions subjecting the valve solenoids to temperatures exceeding the design temperature. No problems were encountered during PCS-1 Phase IV Step 1 tests. A V-54600-04 valve was used for the Hg PMA L/C outlet valve.

To preclude the incidents encountered in SL-1 testing, a high-temperature version of the Valcor V-54600-04 valve has been scheduled for use wherever possible in future applications. This is the Valcor V-54600-06 valve. Five of these valves are on hand, and have been scheduled for use on the TAA for PCS-1 Phase IV Step 2, and on the TAA, Hg PMA, and auxiliary heat-exchanger loop isolation valve in PCS-1 Phase IV Step 3 tests.

Peripheral tests to determine individual valve characteristics were conducted. Results of flow tests with a V-54600-04 valve and a V-54600-06 valve are shown on Figures VI-59 and VI-60. The voltages required to actuate the V-54600-04 valve at 72°F were (a) 0.0 psid - 15 vdc and (b) 350 psid - 28 vdc. The voltages required to actuate the V-54600-06 valve at 72°F were (a) 0.0 psid - 16 vdc and (b) 500 psid - 20 vdc. The maximum solenoid temperature at which the V-54600-06 valve would actuate with 28 vdc and a differential pressure of 0.0 psid was 600°F. To actuate the valve at 500°F with a 0.0 psid differential pressure, 24 vdc were required.

Tests were conducted to determine the feasibility of utilizing a high frequency ac signal input to the solenoids as a vehicle to detect changes in valve position. The tests indicated that this principle was feasible, and this principle has been recommended for additional instrumentation for the L/C valves in PCS-1 Phase IV Step 3 tests.

E. STARTUP SYSTEM

1. Mercury Injection System

Three bellows reservoir ΔP limiting valves were fabricated. Installation of these valves completed the fabrication effort on the three mercury injection systems.

During checkout tests, two systems were operational. However, internal leakage across the safety valve area of the third system (S/N A-3) was indicated. The cause of the leakage was determined to be a countersink in the bellows plate of the S/N A-3 unit that prevented the safety valve from closing completely. The safety valve was removed, reworked, and checkout tests were conducted. The gas regulators were adjusted for a 610 psia outlet pressure.

Unit S/N A-1 (P/N 094583) was packaged along with an isolation (check) valve and shipped to NASA-LeRC. Unit S/N A-2 was designated as available for PCS-1 Phase IV testing. Unit S/N A-3 was designated as a spare.

Electrical wiring additions to the Valcor mercury flow control valves were completed. However, one valve (S/N A-1) was damaged during final electrical checkout tests and was returned to the vendor for repair. Unit S/N A-3 was installed in PCS-1 Phase IV and S/N A-2 has been retained as a spare.

A Test Specification (Ref. 20) and Test Plan (Ref. 15) for testing in PCS-1 Phase IV was completed and tests were conducted during PCS-1

Phase IV Step 1 operation. The tests demonstrated that the mechanical and electrical functions of the valve were not impaired by normal loop environmental conditions after 120.5 hours of mercury-loop operation. Since the valve position was not recorded for any of the Step 1 tests, no numerical correlation with respect to design specifications can be made. However, preliminary evaluations of certain functional valve requirements were made and documented in the Test Report (Ref. 43).

2. Start Programmer (P/N 097260)

Two -X start programmers were fabricated and checked out. The inverter ramp control was fabricated, checked out and installed in each of the start programmers. The start programmer was modified to incorporate lubricant-coolant valve operation for the mercury PMA and the turbine-alternator assembly. This required sensing of frequency and operation of the valves at the selected frequency. Incorporated in the start programmer is the operation sequence, as presently understood, that will start the PCS. However, since no actual start has been made, some changes may be required after the startup tests have been conducted.

The start programmer is designed with spare components installed so that changes can be made with minimum effort. The unit is fully accessible in the test control console so required changes can be made without undue delay to Step 3 testing.

When the performance requirement of the start programmer has been fully established and operation has been demonstrated, it will then be necessary to reconsider the components and circuits from the standpoint of maximum reliability. A circuit of maximum reliability must be designed, fabricated and checked out.

3. Inverter

Two inverters were delivered from Westinghouse to Aerojet during this report period. Figure VI-61 is a photograph of the inverter. Both units have been tested at Aerojet. The second unit was found to have a voltage output curve about 4% higher than the first unit. Both units exhibited some speed instability over a narrow range of speed between 95 and 220 cps. However, the second unit had less tendency to oscillate.

An attempt was made to reduce this oscillation by providing greater voltage regulation of the power supply. This did not reduce the oscillations to a sufficiently low level. A rate feedback circuit was added to the frequency-ramp control circuit which damped the oscillations to an acceptable level.

Tests run separately on the inverter and on NaK and L/C PMAs indicate that the inverter may be able to start the PMAs and operate them satisfactorily through the PCS startup operation. However, the capability of the inverter compared to PMA requirements, as now understood, is marginal. Startup and running tests of the inverter driving the two NaK PMAs and the L/C PMA must be conducted to determine the actual capability of the inverter and PMA system.

F. STEADY-STATE ELECTRICAL CONTROLS

1. Voltage Regulator-Exciter (VR-E)

Four prototype voltage regulator-exciters were completed by the vendor and delivered to Aerojet. These units were laboratory tested to verify the test results obtained at the vendor's plant. Tests were satisfactory.

One of the prototype units has been installed in the low-temperature control assembly (LCA) and the transformer-reactor assembly (TRA) and operation checked. These units are available for PCS-1 Phase IV Step 3 testing.

Tests conducted in RPL-2 have demonstrated that this VR-E is capable of regulating the output voltage of the TAA well within the specified $\pm$ 3% at all load conditions. Tests on the prototype units will be conducted during PCS-1 Phase IV Step 3 testing.

2. Speed Control

The -1 speed control module, the saturable reactor and the power transformer were completed and installed in the LCA and TRA. Laboratory tests were conducted to determine the performance of the -1 speed control modules functioning together. It was found that the transfer curve of the magnetic amplifier was less linear than it had been in the -X speed control. It was established that this was caused by a change in the relative phasing of the magnetic-amplifier power supply and the frequency sensing circuit. A new transformer was designed to be connected for the correct phase relationship. A -X unsealed version of this transformer was fabricated, tested, and installed in the LCA.

A resistance-capacitance stabilizing network, which has been proven out in RPL-2 tests, was fabricated and assembled in the LCA with the speed control module. It was assembled so that adjustments can be made during PCS-1 Phase IV Step 3 testing.

One set of -1 speed control hardware is available. A second set is now in production for use as a spare. It is expected that it will be completed before PCS-1 Phase IV Step 3 testing.

Tests made on the preprototype speed control system with the TAA in RPL-2 demonstrated that it holds the frequency well within the specified 400 cps $\pm$ 1% when the vehicle load is changed from no load to full load. The speed controller has also been shown to be stable under all operating conditions. It was also demonstrated that a vehicle load of 36 kw could be suddenly added or removed without severe disturbance and that full recovery was achieved in 1.9 seconds when load was added and in 1.0 seconds when load was removed.

The performance of the prototype system will be demonstrated during PCS-1 Phase IV Step 3 testing.

3. Low-Temperature Control Assembly (LCA) (P/N 097054-1)

Fabrication of this assembly was completed; modules were installed, and tests were completed satisfactorily. Combination tests with parts mounted in the TRA were conducted, and this unit is now available for PCS-1 Phase IV Step 3 testing.

Figure VI-62 is a photograph of the partially completed LCA. The voltage regulator module and the speed control module are shown mounted on the heat sink.

4. Transformer Reactor Assembly (TRA) (P/N 097760-1)

Machining and fabrication of this unit was completed. The wound components were mounted in it and tests were successfully completed. Combination tests were conducted with the LCA, and this unit is now available for use in PCS-1 Phase IV Step 3 tests.

Figure VI-63 is a photograph of the partially completed TRA. The saturable reactor and the saturable current potential transformer are shown mounted on the liquid-cooled heat sink. The purpose of this TRA is to provide a convenient assembly of the high-temperature control components and to provide a thermal environment that will cause the mounted components to operate at temperatures approximating those expected in space application. The heat sink will be maintained by a flowing liquid at the temperature expected in a mission application. This will ensure that the electrical insulation operates at hot-spot temperatures approximating those expected in final service. Endurance testing on the unit will thus provide a more valid test of insulation life.

5. Parasitic Load Resistor (PLR) (P/N 097223)

The pressure drop across the PLR, as determined with water, was found to be 0.5 psi at 40,200 lb/hr flow. Also, NaK inventory was checked by measuring the weight of water required to fill the PLR. Translated to NaK, the weight of NaK at 1100°F was found to be 21.7 lb.

A suspended mounting structure for mounting the PLR in the PCS-1 loop was designed and fabricated. The PLR (SN-2) was installed during PCS-1 Phase IV Step 1 testing, although it was not connected electrically.

TABLE VI-1

SPECIFIED AND REPORTED CHEMICAL COMPOSITION AND GAS CONTENT AISI M-50 BEARING STEEL (FIRST HEAT) (AEROJET SPECIFICATION AGC-10354)

A. Chemical Composition

Element	Specified Minimum %	Specified Maximum %	Reported[1]	Percent of Accuracy of Determination
Carbon	0.77	0.85	0.822	±5
Manganese	0.20	0.30	0.29	±5
Silicon	0.15	0.25	0.20	±5
Chromium	3.75	4.25	4.00	±2
Molybdenum	4.00	4.50	4.15	±2
Vanadium	0.90	1.10	0.98	±2
Nickel		0.07	0.07	±2
Copper		0.08	0.01	±5
Aluminum		0.01	0.03	±2
Iron	Balance	Balance		±10
Maximum Content of Trace Elements				
Cobalt		0.25	0.02	±10
Tungsten		0.25	0.08	±10
Titanium		0.30	<0.01	±10
Phosphorus		0.01	0.007	±10
Sulphur		0.01	0.006	±10
Arsenic		0.01	ND[2]	±10
Lead		0.0005	ND	±10
Tin		0.05	0.02	±10
Magnesium		0.01	<0.01	±10
Columbium		0.1	<0.01	±10

[1] For vacuum induction melt.

[2] Not detected.

TABLE VI-1 (cont.)

Element	Specified Minimum %	Specified Maximum %	Reported	Percent of Accuracy of Determination
Gold		(3)	(4)	±10
Bismuth				±10
Zirconium				±10
Silver				±10
Antimony				±10
Boron				±10
Zinc				±10
Cadmium		(3)	(4)	±10
B. Gas Content				
Nitrogen		0.005	0.0038	±15
Oxygen		0.005	0.0026	±15
Hydrogen		0.001	<0.0001	±15

(3) These elements are not desirable; however, if they are expected to be traceable the maximum percentage is to be reported to Aerojet for approval.

(4) Not reported for this melt.

TABLE VI-2

SPECIFIED AND REPORTED CHEMICAL COMPOSITION AND GAS CONTENT
AISI M-50 BEARING STEEL (SECOND HEAT)
(AEROJET SPECIFICATION AGC-10354)

A. Chemical Composition

Element	Specified Minimum %	Specified Maximum %	Reported Vacuum Induction	Reported 1st Vacuum Arc Remelt	Percent of Accuracy of Determination
Carbon	0.77	0.85	0.802	0.824	±5
Manganese	0.20	0.30	0.29	0.23	±5
Silicon	0.15	0.25	0.22	0.20	±5
Chromium	3.75	4.25	4.22	4.22	±2
Molybdenum	4.00	4.50	4.18	4.35	±2
Vanadium	0.90	1.10	0.96	0.98	±2
Nickel		0.07	0.06	0.06	±2
Copper		0.08	0.03	0.01	±5
Aluminum		0.01	0.01	0.01	±2
Iron	Balance	Balance			±10
Maximum Content of Trace Elements					
Cobalt		0.25	0.02	0.03	±10
Tungsten		0.25	0.04	NA(1)	±10
Titanium		0.30	<0.01	<0.01	±10
Phosphorus		0.01	0.010	0.008	±10
Sulphur		0.01	0.007	0.007	±10
Arsenic		0.01	ND(2)	ND	±10
Lead		0.0005	ND	ND	±10
Tin		0.05	0.02	<0.03	±10
Magnesium		0.01	<0.01	<0.01	±10
Columbium		0.1	<0.05	<0.05	±10

(1) Not analyzed.
(2) Not detected.

TABLE VI-2 (cont.)

Element	Specified Minimum %	Specified Maximum %	Reported Vacuum Induction	Reported 1st Vacuum Arc Remelt	Percent of Accuracy of Determination
Gold		(3)	ND	ND	±10
Bismuth		↓	ND	ND	±10
Zirconium		↓	ND	ND	±10
Silver		↓	ND	ND	±10
Antimony		↓	ND	ND	±10
Boron		↓	ND	ND	±10
Zinc		↓	ND	ND	±10
Cadmium		(3)	ND	ND	±10
B. Gas Content					
Nitrogen		0.005	0.0040	NA	±15
Oxygen		0.005	0.0014	NA	±15
Hydrogen		0.001	0.0001	NA	±15

(3) These elements are not desirable; however, if they are expected to be traceable, the maximum percentage is to be reported to Aerojet for approval.

TABLE VI-3

EVENTS DURING THE 3000-HOUR NaK PMA ENDURANCE TEST
AND PERIPHERAL TESTING THEREAFTER

	Completion Date	
*2	7/22/65	Series of starts at ambient temperature
10	7/23/65	Series of starts at 500°F, then cool to ambient and restart
20	7/23/65	Thermal map of PMA at HRL conditions (500°F)
30	H-Q 7/23/65 NPSH 7/26/65	Series of H-Q and min NPSH runs at HRL conditions
60	7/26/65	Series of tests for speed-torque curve at HRL conditions
80	7/26/65	Plugging and purification runs at HRL conditions
120	7/28/65	Shutdown, cool to 400°F, startup and heat to 1170°F at 10°/min
125	8/4/65	Series of starts at PNL conditions (1170°F)
130	8/5/65	Thermal map of PMA at PNL conditions
140	9/13/65	Series of H-Q and min NPSH runs at PNL conditions
160	9/14/65	Plugging and purification runs at PNL conditions
170	Approx. every 10 days	Maintain PNL steady state conditions, checking purification of loop once/week or as required to maintain purity level of 20 ppm
2800		Rerun H-Q and min NPSH tests at PNL conditions
2850		Cool to HRL conditions and rerun H-Q and min NPSH tests
2860		Return to PNL conditions and complete 3000 hr test
3000		Shutdown, return to ambient, run series of restarts. Remove PMA from loop, clean and disassemble. Examine all parts and write final report

*Approximate time of event during endurance and peripheral tests (hr).

TABLE VI-4

DESIGN CONDITIONS, SIGNIFICANT DIMENSIONS, AND FABRICATION MATERIALS OF THE -1 TUBE-IN-SHELL BOILER

Design Parameters	Dimensions and Materials
NaK	Shell
Inlet Temperature - 1305°F	OD (in.) = 24
Inlet Pressure - 41 psia	ID (in.) = 17.6
Temperature Drop - 170°F	Wall (in.) = 0.187
Mercury	Length (in.) = 45 (including toroids)
Flow Rate - 11,500 lb/hr	Material - 316 SS
Inlet Temperature - 515°F	Tubing
Outlet Temperature - 1280°F	OD (in.) = 0.902
Inlet Pressure - 340 psia	Wall (in.) = 0.125
Outlet Pressure - 270 psia	Length (ft) = 60
Size	Material - 9M (SSTU Type 9Cr1Mo)
Overall length - 55 in.	Plug Inlet
Diameter - 24 in.	Length (ft) = 10
Tube Length - 60 ft	Plug (red) OD (in.) = 0.602 - 0.599
Boiler Weight - 850 lb	Wire Pitch = 3 in. pitch for 1st 3 ft of plug length 4 in. pitch for next 2 ft of plug length 5 in. pitch for remainder of plug length
Inventories	Material - 1020 rod (solid) - 1010 wire 0.135-in. OD
NaK - 150 lb	Ribbon Turbulator
Mercury - 20 lb	Length = 17-1/2 ft (average)
	Pitch = 7.3 in.
	Material - 0.016 in. sheet steel type C1009

TABLE VI-5

COMPARISON OF T-T BOILER PERFORMANCE IN PCS-1/SL-1 BEFORE AND AFTER INJECTION OF RUBIDIUM

Parameter	Before Rb	After Rb
NaK Conditions		
Flow rate (lb/hr)	47,500	45,500
Inlet temperature (°F)	1306	1310
Outlet temperature (°F)	1136	1135
Mercury Conditions		
Flow rate (lb/hr)	11,750	11,700
Inlet temperature (°F)	412	396
Outlet temperature (°F)	1285	1298
Exit pressure (psia)	279 ±15	266 ±2
Inlet pressure (psia)	311	310
Pressure drop (psi)	32	44
Plug section pressure drop (psi)	15	18
Carryover (%)	2 ±5	3 ±5
Excess superheat length (ft)	13	18

TABLE VI-6

PARAMETER VALUES FOR TUBE-IN-TUBE BOILER TESTS

P_{BO}	ΔT_N	TNI °F	10,000 lb/hr	12,000 lb/hr
$P_{BO} = 270$	$\Delta T_N = 190$	1330	1	25
		1305	2	26
		1280	3	27
		1250	4	28
	$\Delta T_N = 180$	1330	5	29
		1305	6	30
		1280	7	31
		1250	8	32
	$\Delta T_N = 170$	1330	9	33
		1305	10	34
		1280	11	35
		1250	12	36
$P_{BO} = 245$	$\Delta T_N = 190$	1330	13	37
		1305	14	38
		1280	15	39
		1250	16	40
	$\Delta T_N = 180$	1330	17	41
		1305	18	42
		1280	19	43
		1250	20	44
	$\Delta T_N = 170$	1330	21	45
		1305	22	46
		1280	23	47
		1250	24	48

Boiler inlet mercury temperature = 505°F

TABLE VI-7

PARAMETER VALUES FOR BOILER STARTUP PRESSURE DROP EVALUATION

Condition	Pressure-Boiler Out (psia)	Mercury Flow Rate (lb/hr)
1*	270	11,500
2	270	10,320
3	233	11,500
4	233	10,320
5	233	9,200
6	233	8,050
7	216	11,500
8	216	10,320
9	216	9,200
10	216	8,050
11	189	10,320
12	189	9,200
13	189	8,050
14	189	6,900
15	162	9,200
16	162	8,050
17	162	6,900
18	162	5,750
19	135	8,050
20	135	6,900
21	135	5,750
22	135	4,600

*Condition 1:

$\dot{w}_{Hg}$ = 11,500 lb/hr

$T_{NaK\ IN}$ = 1305°F

ΔT_{NaK} = 170°F

P_{BO} = 270 psia

NOTE:

After Condition 1 is established, no further change is to be made in NaK flow rate and NaK inlet temperature

TABLE VI-8

COMPARISON OF SNAP-8 BOILERS - TUBE-IN-TUBE AND TUBE-IN-SHELL

	Tube-in-Shell (P/N 092020)		Tube-in-Tube (P/N 097444)	
Design				
Material	9M		Modified 9M	
Tube length (ft)	60		30	
Hg heat transfer area (ft^2)	57		36	
Wet weight (lb)	850		480	
Overall mechanical design	Fair		Good	
Diagnostic capability	Poor		Good	
Design flexibility				
Internal plug config.	Poor		Good	
Configuration	Poor		Good	
Producibility	Fair		Good	
Lead time (9M tubing assumed available)	4 mo		3 mo	
Conditioning Period (hr)				
RPL-2 test loop	600		42	
PCS-1/SL-1 test loop	26		26	
W-1 test loop	>200		-	
Performance at Rated Flow Rates	Without Rb	With Rb	Without Rb	With Rb
Terminal Temperature Difference				
RPL-2 test loop	≤50	≤50	≤30	-
SL-1 test loop	≤50	-	≤30	30
Outlet Pressure Fluctuations (psi)				
RPL-2 test loop	±6-9	±6-9	±3.5	-
SL-1 test loop			±15	±2.5
Liquid Carryover (%)				
RPL-2 test loop	6	6	Low (insuff. data)	-
SL-1 test loop	7-10	-	2 ±5	3 ±5
Hg Pressure Drop (psi)				
RPL-2 test loop	135	135	80	-
SL-1 test loop	100	-	50	60

TABLE VI-9

SNAP-8 -1 CONDENSER DESIGN PARAMETERS

Design Parameters

NaK flow rate - 35,000 lb/hr

Inlet temperature - 496°F

Inlet pressure - 52.9 psia

Outlet temperature - 696°F

Outlet pressure - 45.9 psia

Mercury flow rate - 11,500 lb/hr

Inlet temperature - 680°F

Outlet temperature - 505°F

Inlet pressure - 15.5 psia

Outlet pressure - 12.0 psia

Size - Overall Length - 61.2 in.

Diameter - 10.2 in. max

Tube length - 51.5 in. max

Condenser weight - 120.2 lb wet

Inventories - NaK - 32.6 lb

Mercury - capable of storing 17.6 lb of Hg and operating satisfactorily during the loss of the 10 lb during 10,000 hr of operation

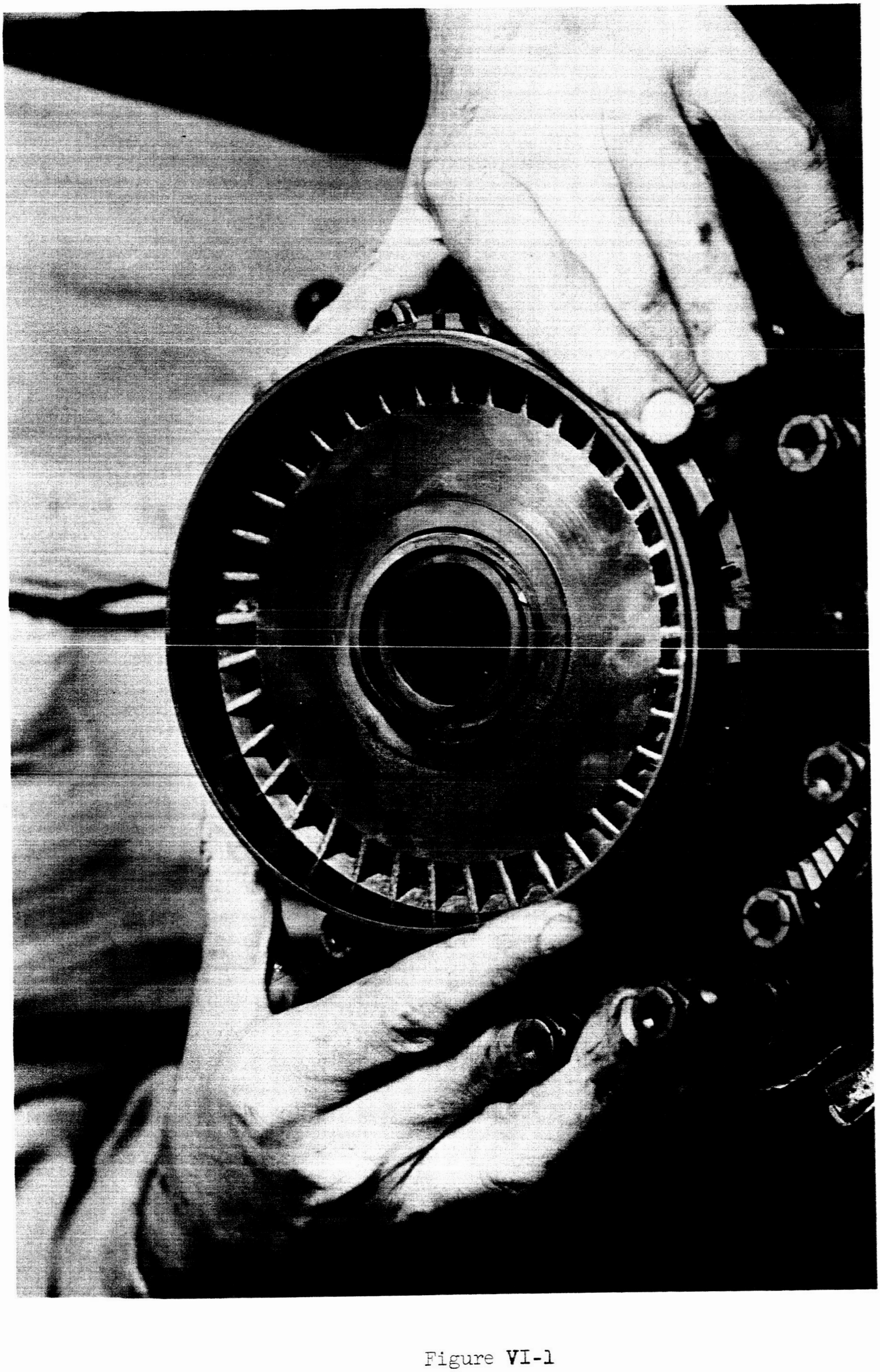
TABLE VI-10

CONDENSER TEST CONDITIONS
(Reference 2)

Test Condition	T_{NCI} (°F)	L_c (in.)	P_{HCI} (psia)	W_N (lb/hr x 10^{-3})
1	500	45	10	As required to reach 10 psia
2		35	-	Same as in Test Condition 1
3		25	-	Same as in Test Condition 1
4		45	15.5	As required to reach 15.5 psia
5		35	-	Same as in Test Condition 4
6		25	-	Same as in Test Condition 4
7		20	-	Same as in Test Condition 4
8		45	20.0	As required to reach 20 psia
9		35	-	Same as in Test Condition 8
10	500	25	-	Same as in Test Condition 8
11	450	45	10	As required to reach 10 psia
12		35	-	Same as in Test Condition 11
13		25	-	Same as in Test Condition 11
14		45	15.5	As required to reach 15.5 psia
15		35	-	Same as in Test Condition 14
16		25	-	Same as in Test Condition 14
17		20	-	Same as in Test Condition 14
18		45	20	As required to reach 20 psia
19		35	-	Same as in Test Condition 18
20	450	25	-	Same as in Test Condition 18

NOTE: X_C = 0.90/1.00 for all tests.

First 20 test conditions run at mercury flow rate of 10,000 lb/hr. Repeat all test conditions (T.C. 21-40) at 12,000 lb/hr mercury flow.

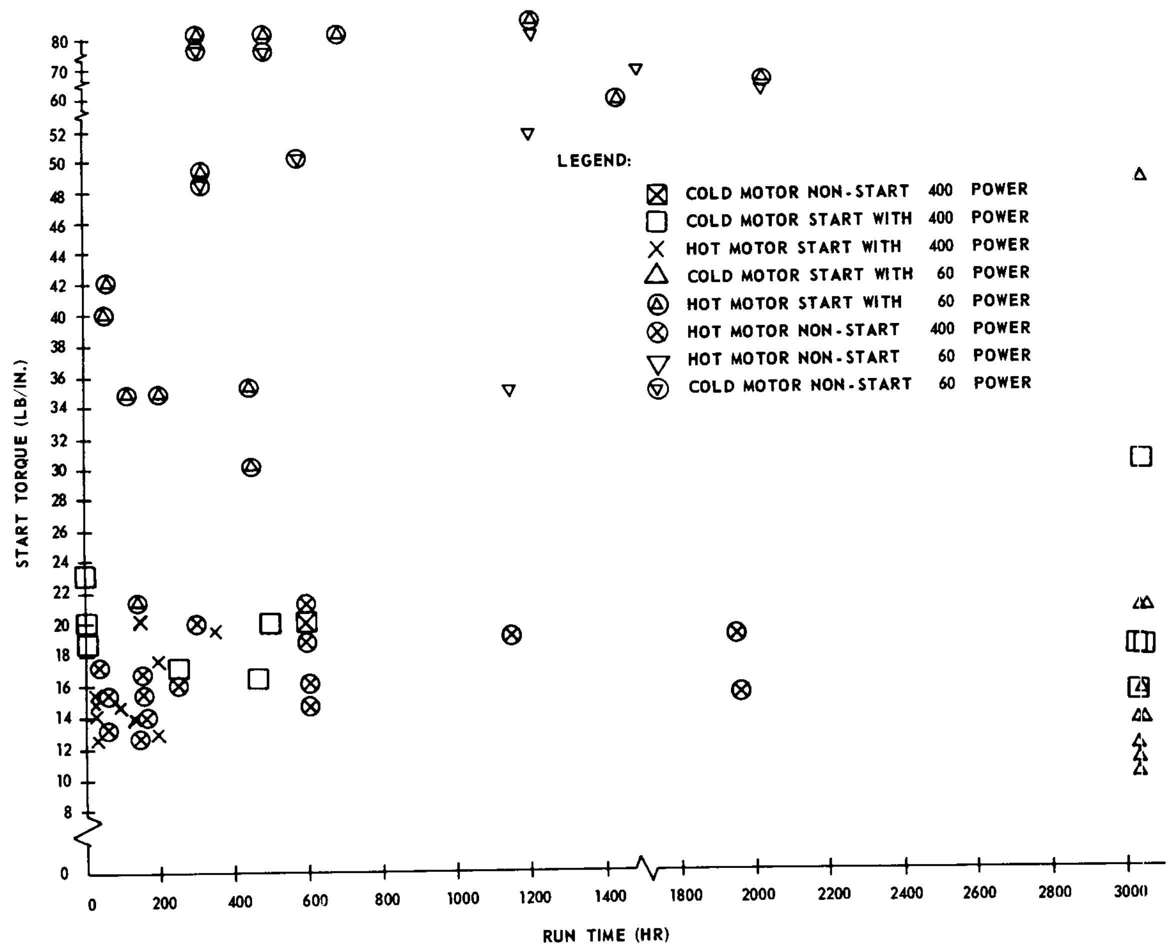


Third Stage Nozzle Diaphragm Inlet Showing Loose Spirolox Retaining Ring

665-497

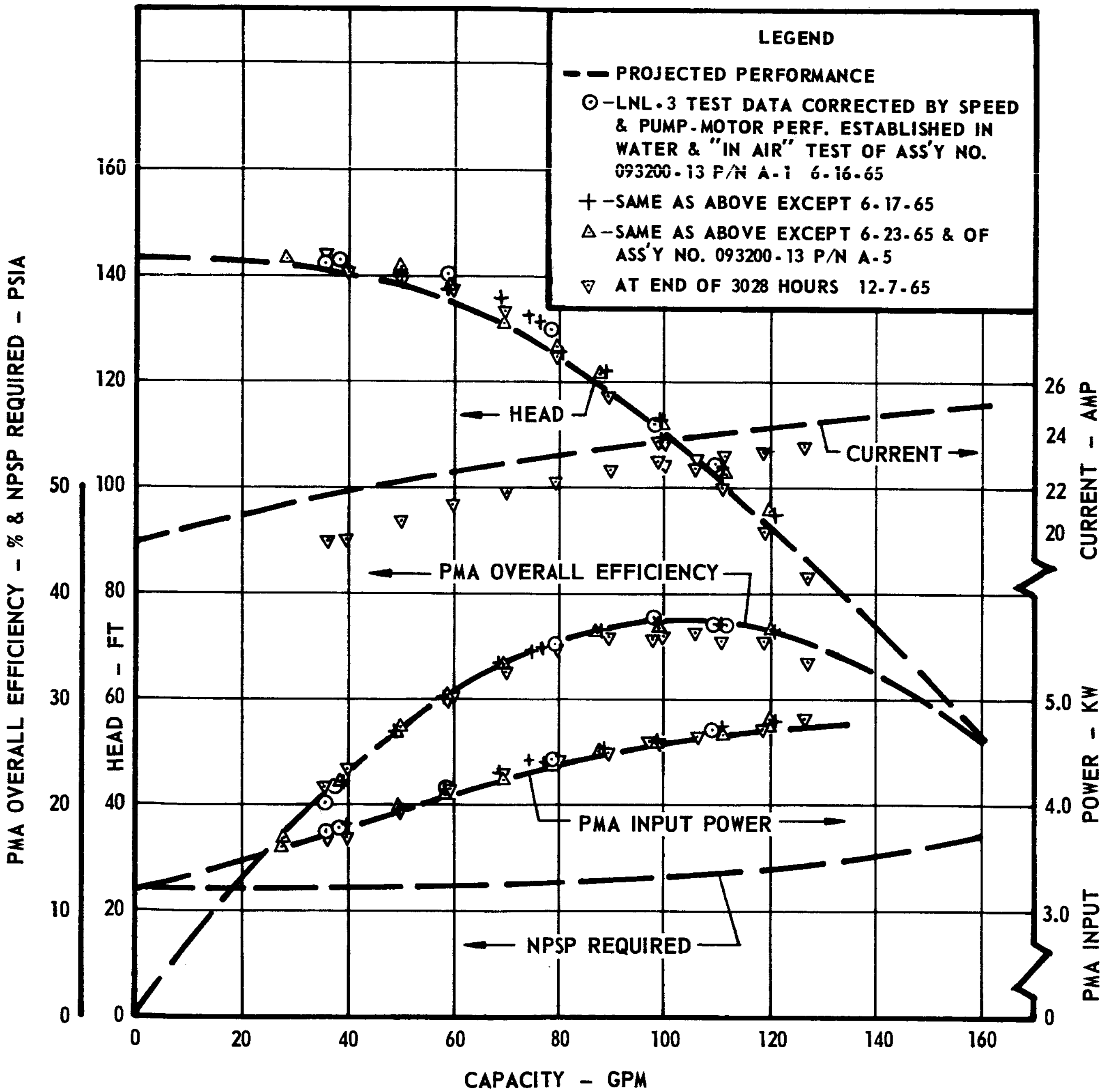
Figure VI-1

A366-NF-1163

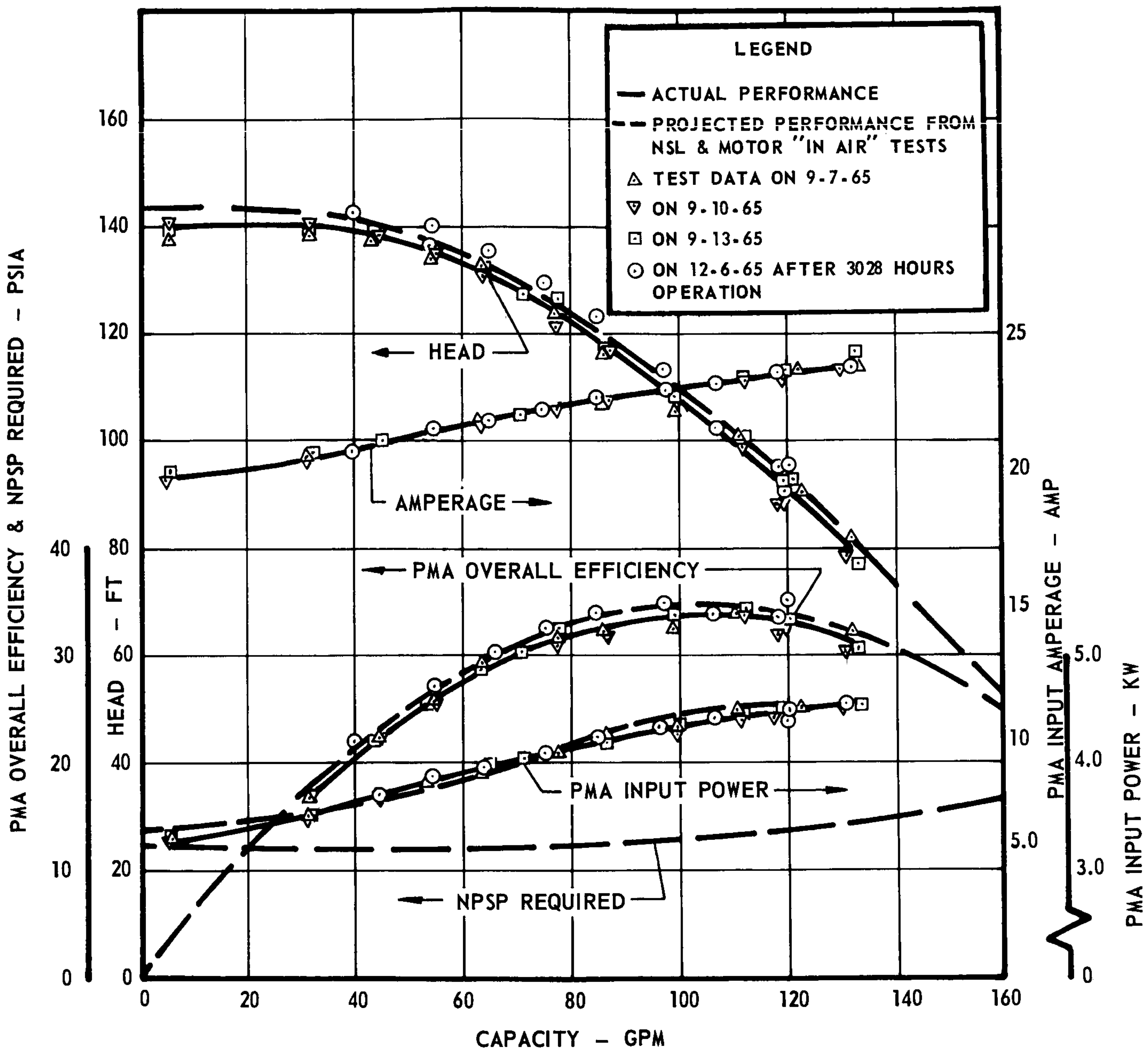


Starting Torque vs Time - NaK PMA (P/N 093200-13, S/N A-5) Testing in LNL-3 (7-22-65 through 12-6-65) with 78 Starts During Test, 60 Starts Following Test, Total Run Time 3027 Hr.

Figure VI-2

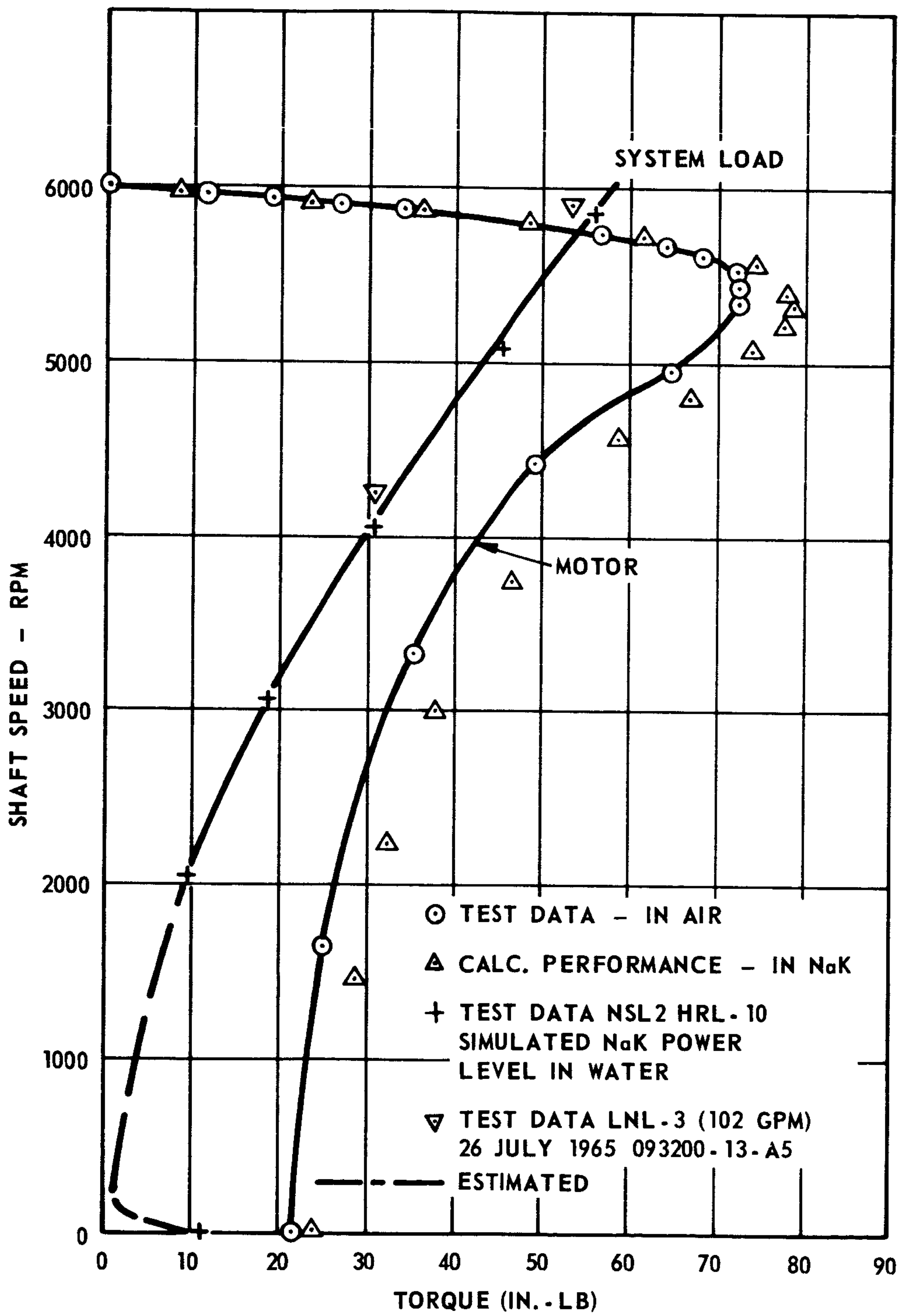


NaK Pump-Motor Assembly (P/N 093200-13, S/N A-5)
Performance Curve at 495°F in LNL-3



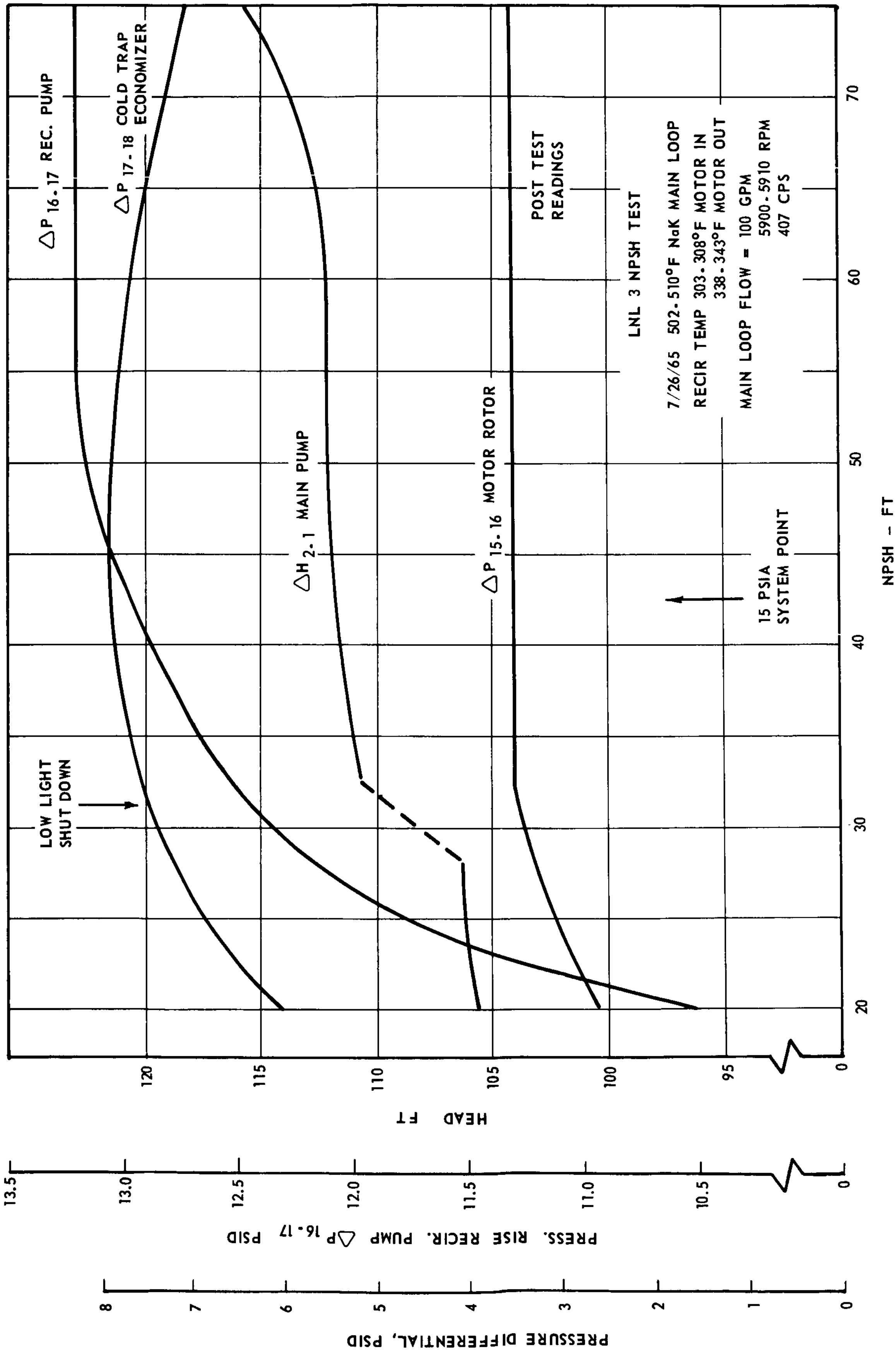
NaK PMA (P/N 093200-13, S/N A-5) Performance Curve
at 1170°F in LNL-3

Figure VI-4



Heat Rejection Loop Motor-Speed Torque - 208 Volts, 400 Hz (cps)

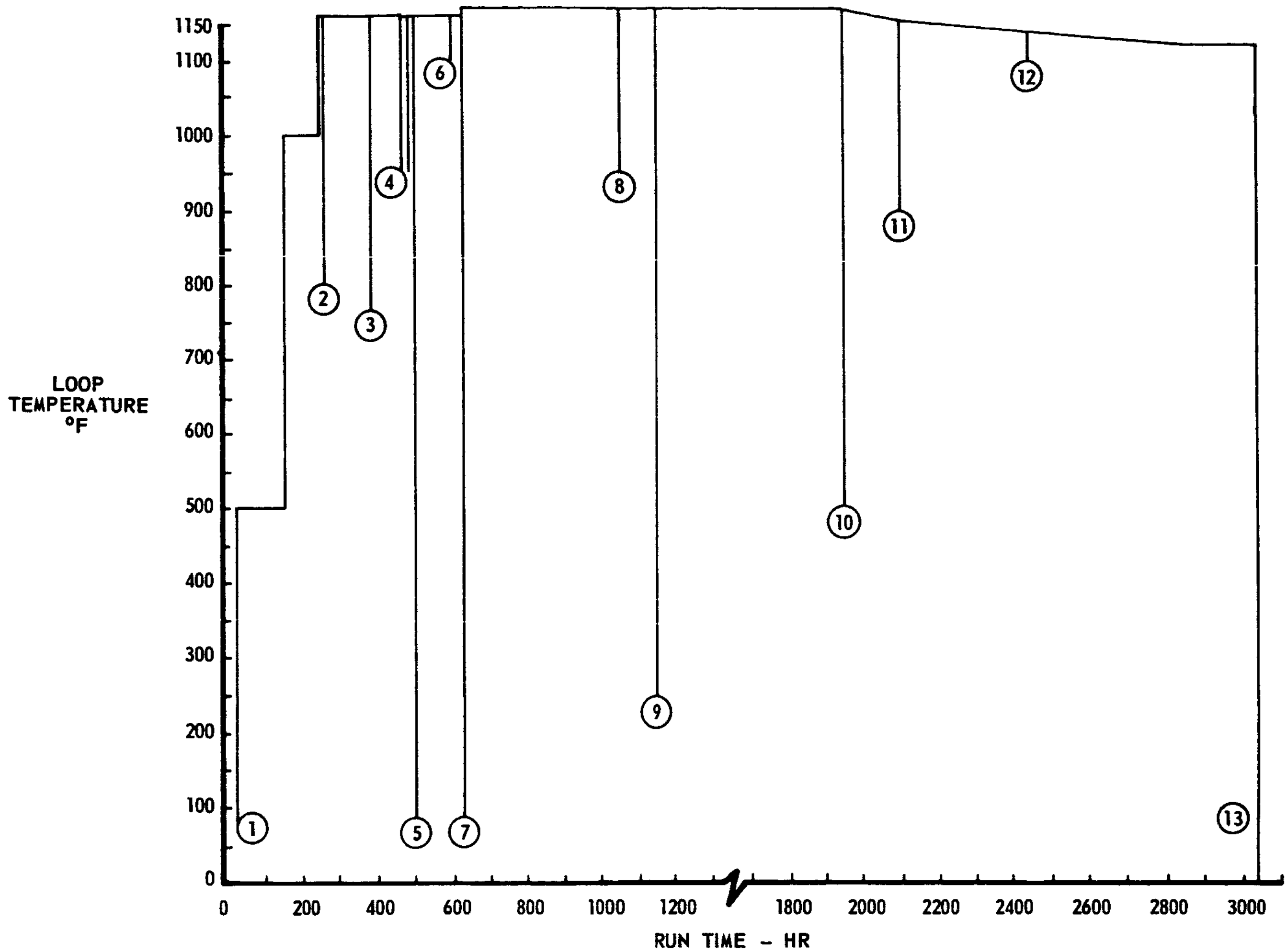
Figure VI-5



LNL-3 NPSH Test

A366-NF-1162

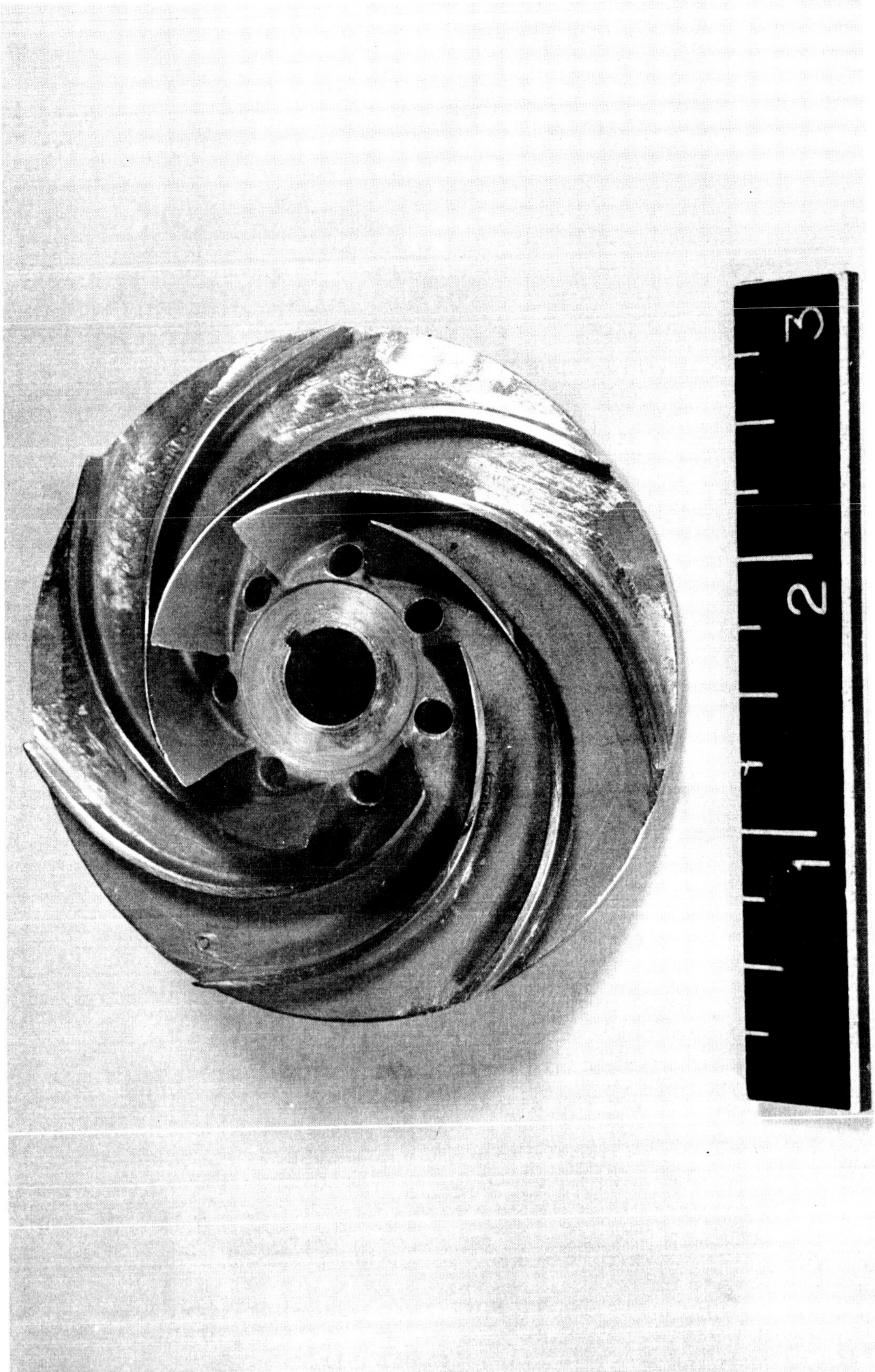
Figure VI-6



1. 48-hr Controlled Shutdown 7-23-65
2. 1-hr Shutdown - Level Probe Repair 8-7-65
3. 2-hr Shutdown - Power Failure 8-11-65
4. Two 7-hr Shutdowns - Breaker Overload 8-15-65
5. 33-hr Shutdown - Heater Repairs 8-16-65
6. 1-hr Shutdown - Breaker Overload 8-22-65
7. 98-hr Shutdown - M-G Set Replacement 8-23 to 8-27-65
8. Low Temperature - No Shutdown 9-14-65
9. 6-hr Shutdown - Power Failure 9-18-65
10. 4.2-hr Shutdown - Breaker Overload 10-22-65
11. 1-hr Shutdown - M-G Set Repair 10-26-65
12. Low Temperature - No Shutdown
13. Loop Shutdown - End of Test Program (3028 hr) 12-6-65

LNL-3 Loop Temperature vs Time During NaK Pump-Motor Assembly Testing from 22 July to 6 December 1965

Figure VI-7



Lube/Coolant Pump-Motor Assembly (P/N 093580, S/N 481501)
Impeller After 4652 Hours Total Operating Time

166-431

Figure VI-8

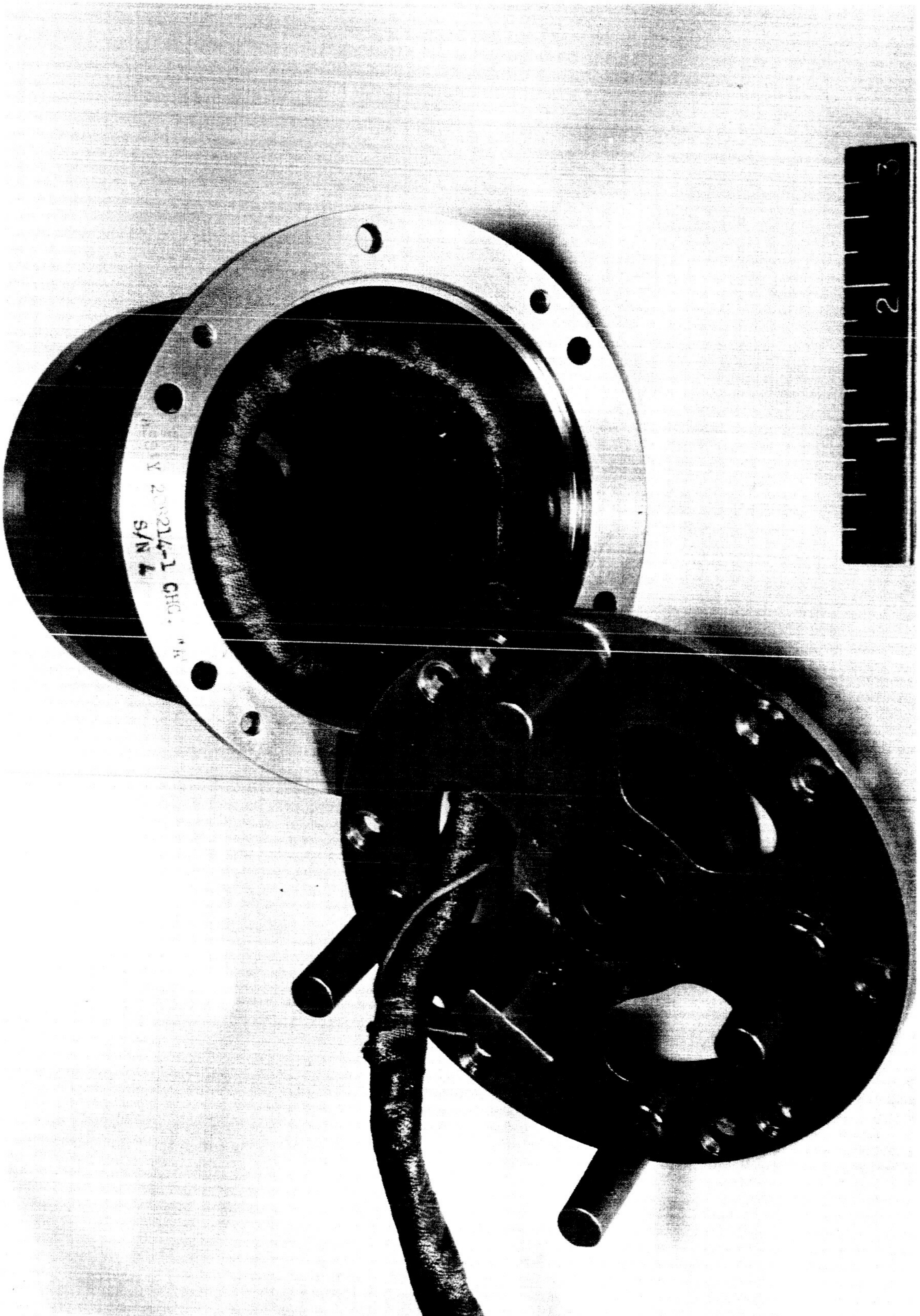
Lube/Coolant Pump-Motor Assembly (P/N 093580, S/N 481501)
Thrust Bearing Surface After 4652 Hours Total Operating Time

Figure VI-9

Lube/Coolant Pump-Motor Assembly (P/N 093580, S/N 481501),
Rotor Showing Speed Sensor End Bearing Journal After
4652 Hours Total Operating Time

166-430

Figure VI-10

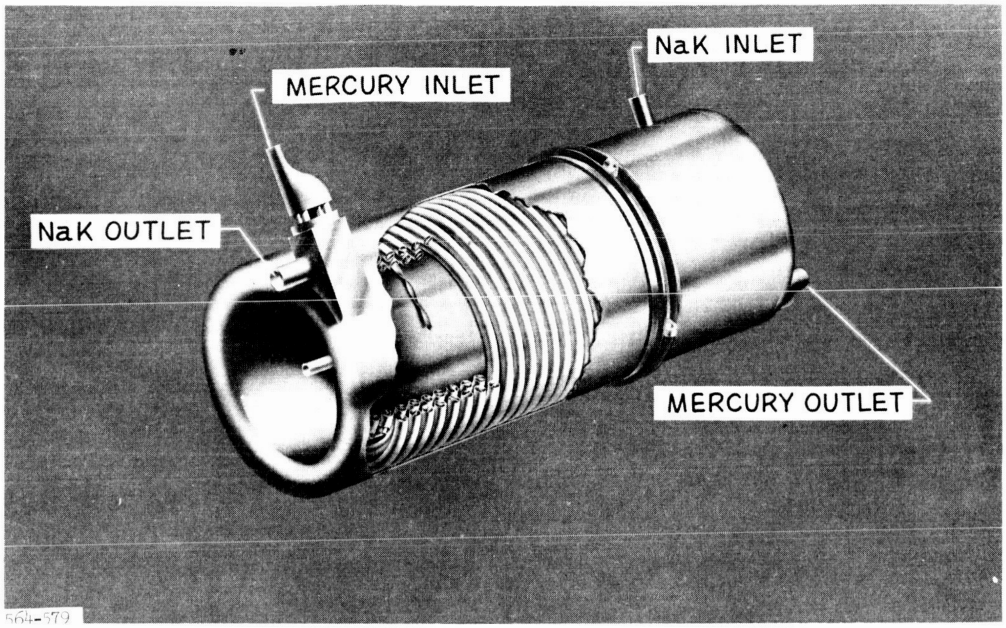


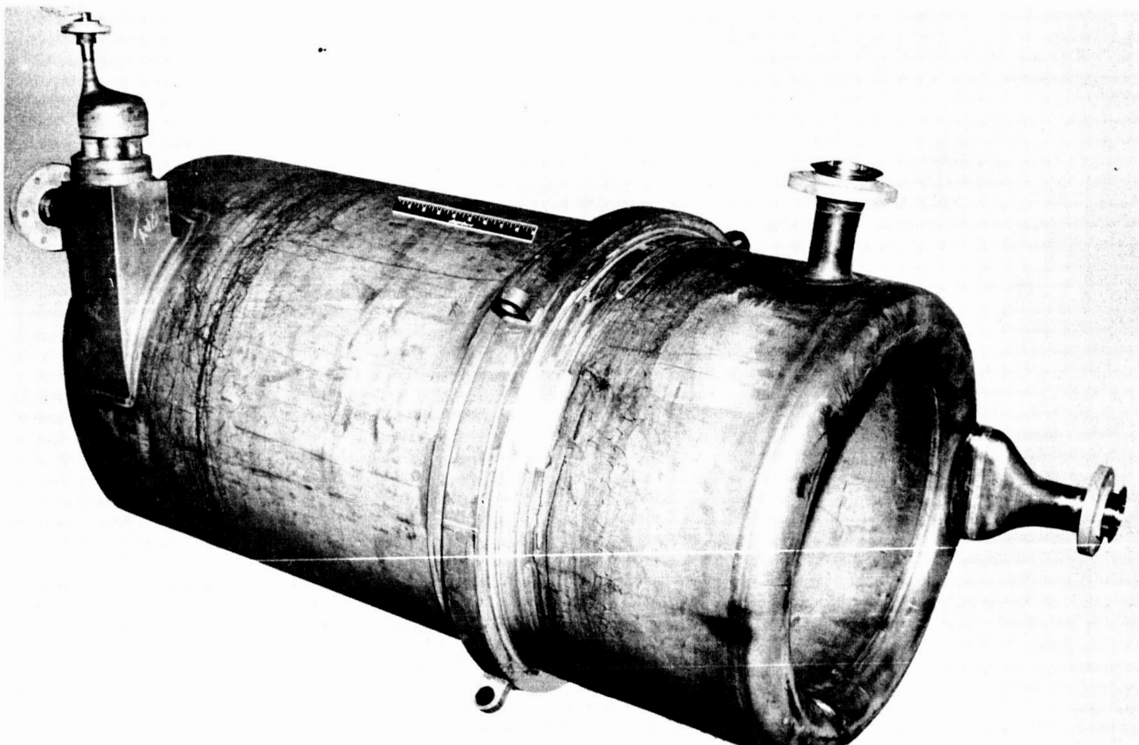
Lube/Coolant Pump-Motor Assembly (P/N 093580, S/N 481501)
Stator and End Bell After 4652 Hours Total Operating Time

166-427

Figure VI-11

A366-NF-1141

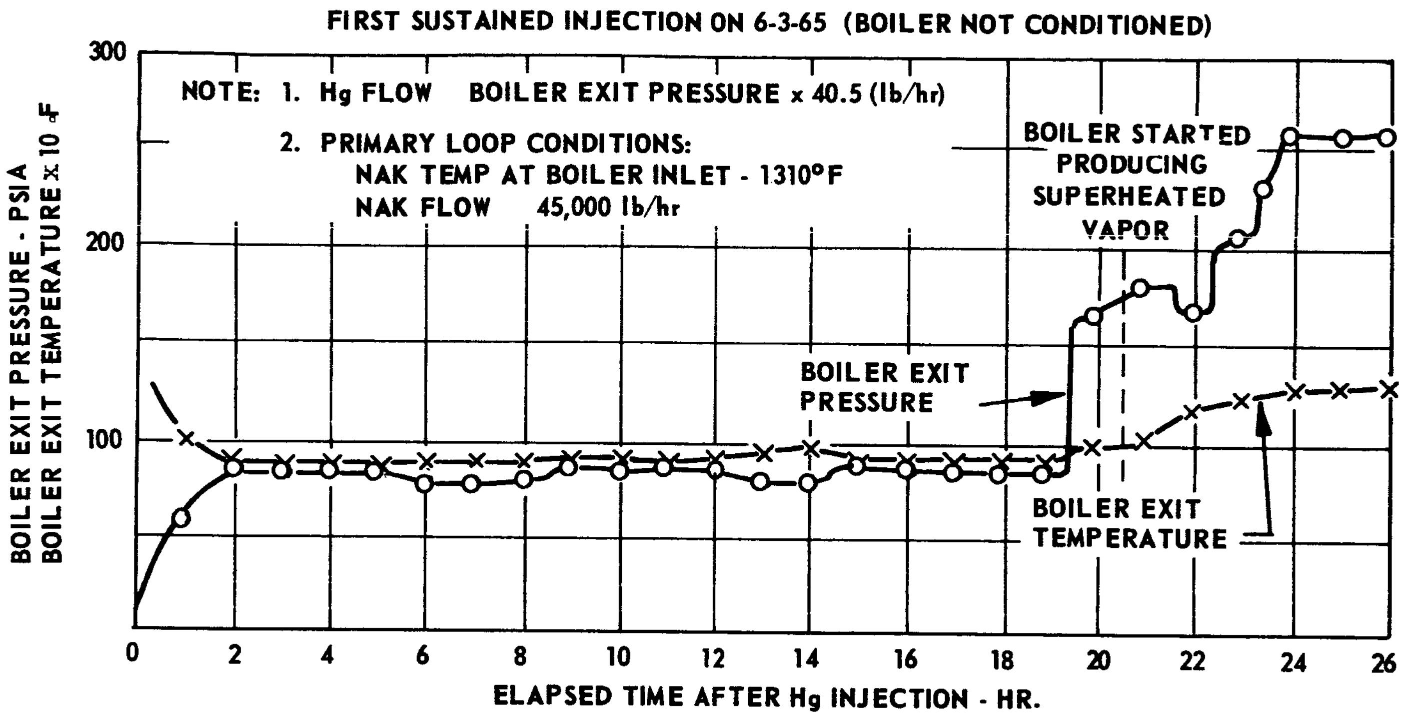


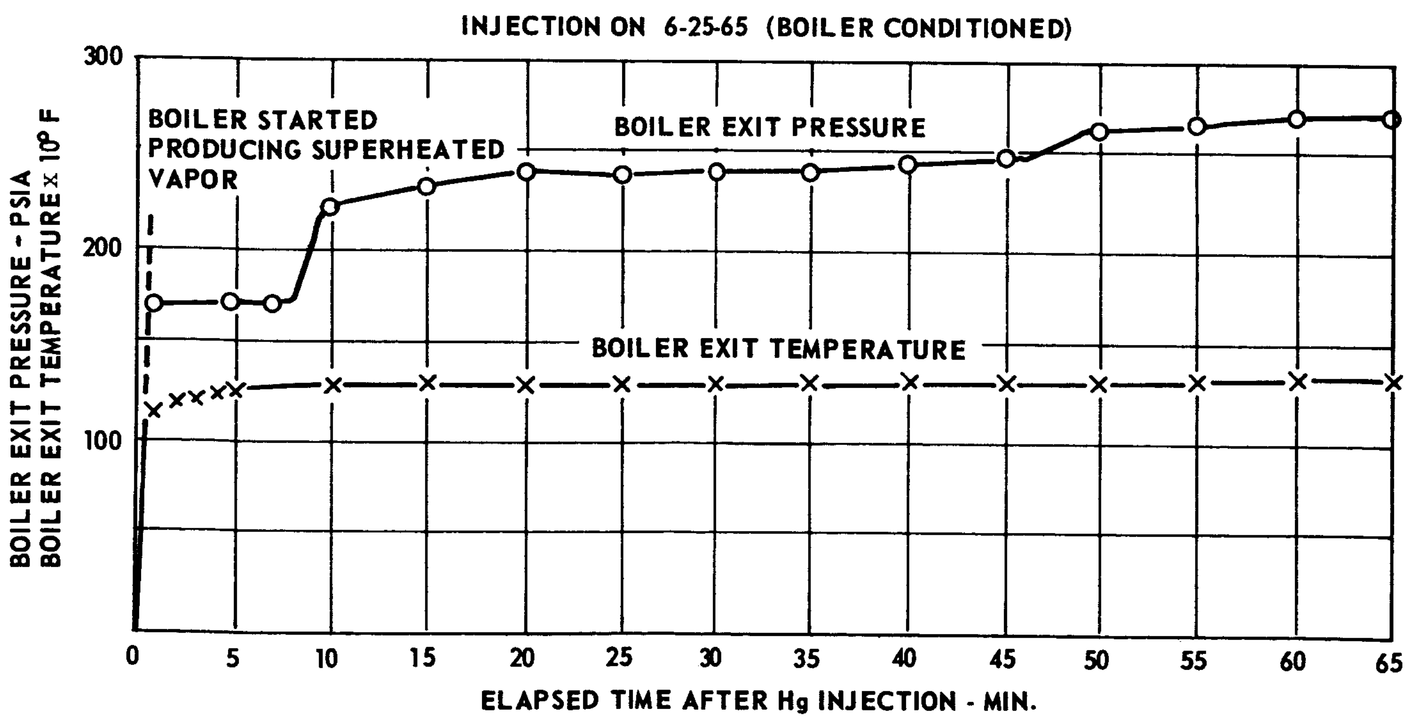


SNAP-8 Tube-in-Shell Boiler (P/N 092952-3) and
Cutaway Drawing Showing Cross-Counter Flow

Figure VI-12

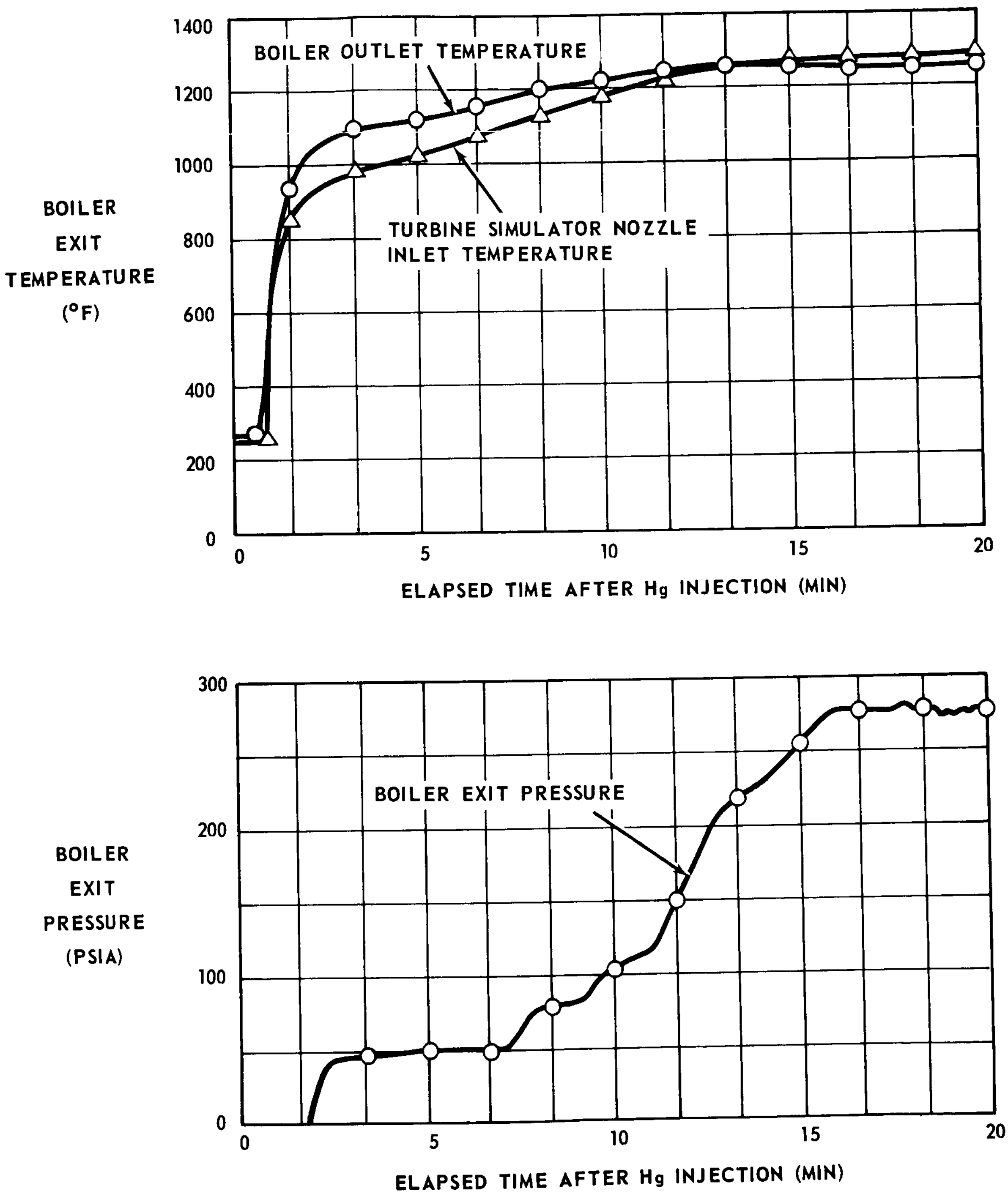
A1165-NF-1034





Boiler Behavior After Hg Injection During PCS-1/SL-1
Phase I Testing

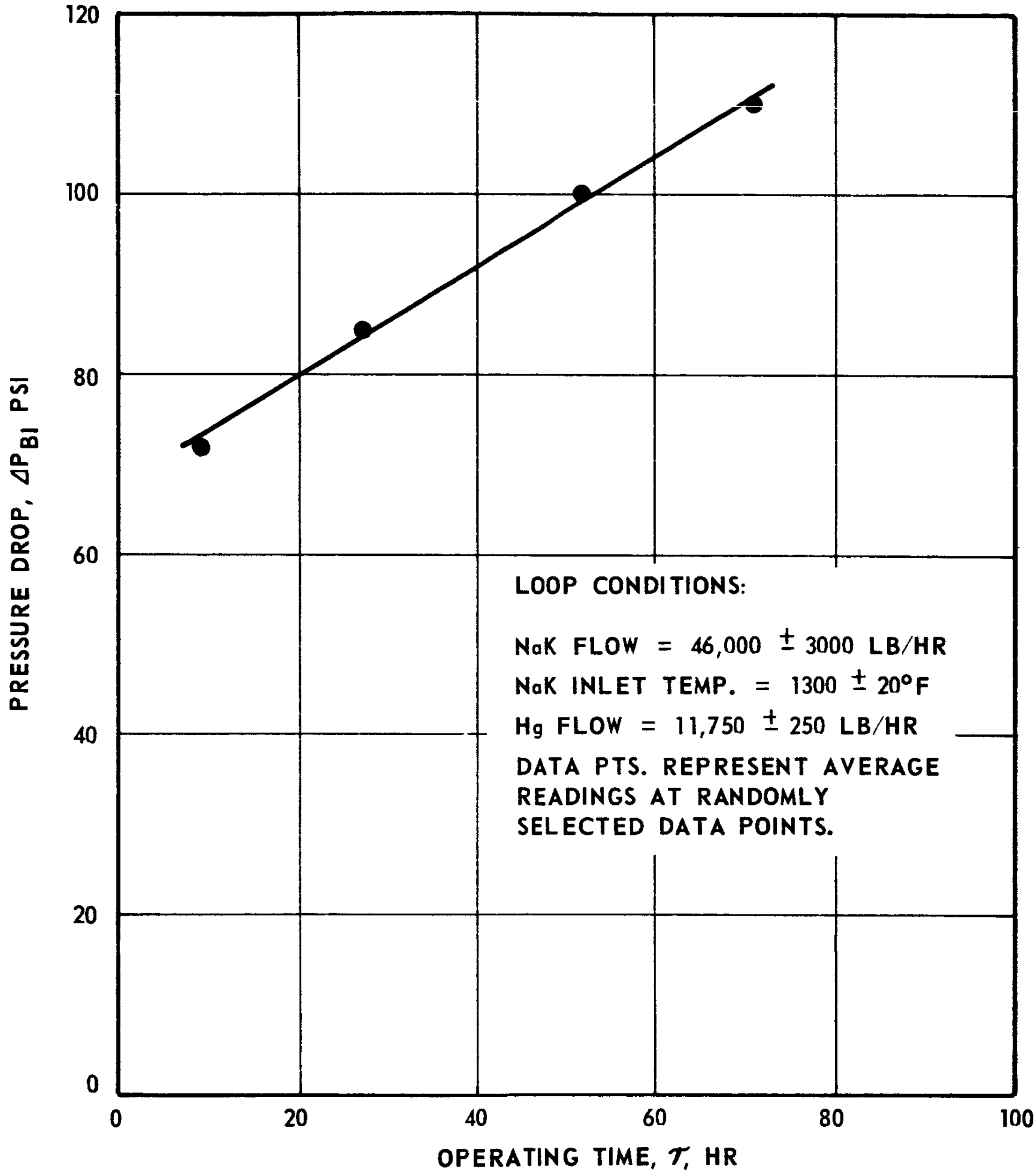
Figure VI-13



Boiler Behavior After Standard Hg Flow Ramp

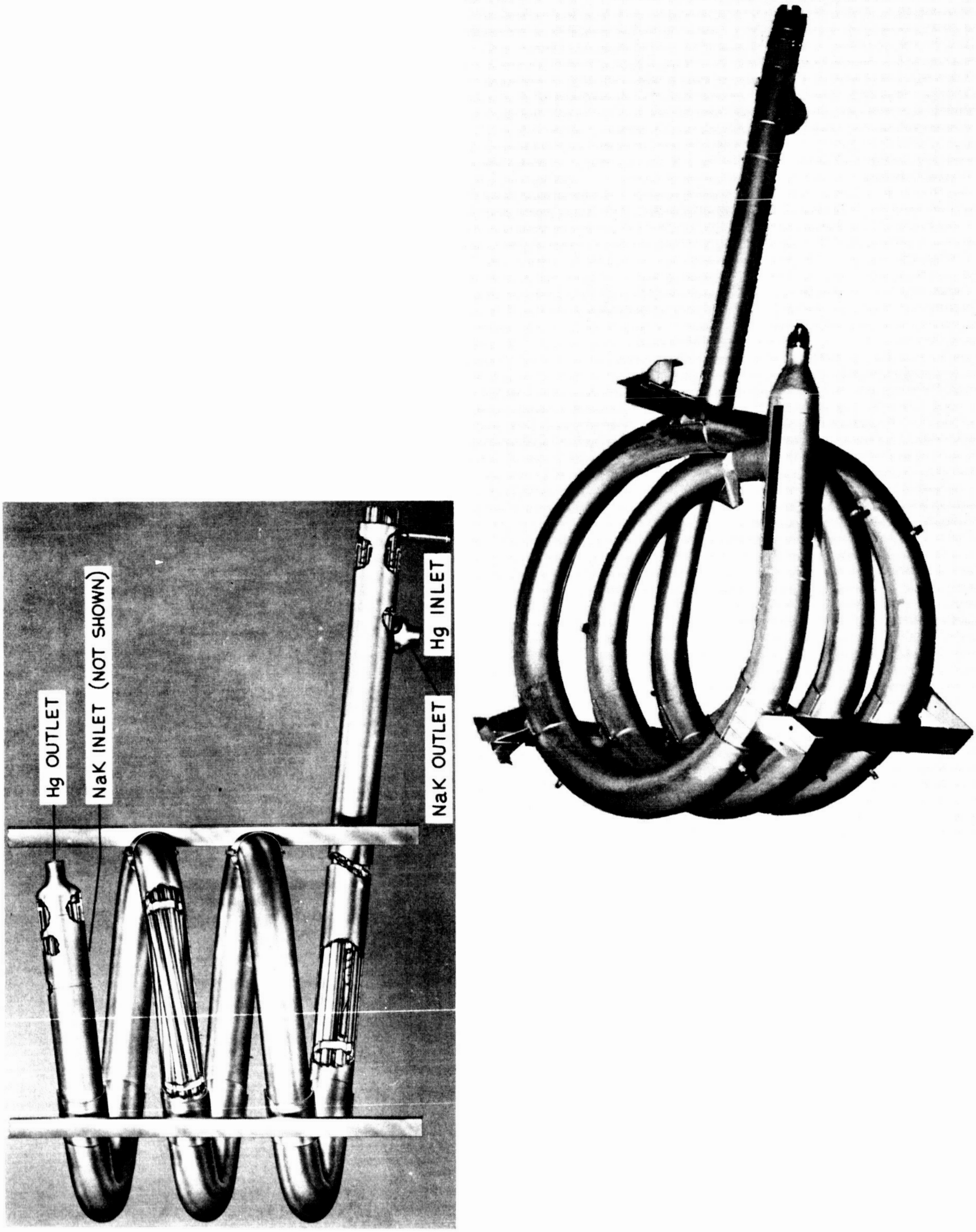
Figure VI-14

A366-NF-1143



Hg-Side Pressure Drop with Operating Time Tube-in-Shell Boiler (P/N 092952-1, S/N A-4) During PCS-1/SL-1 Testing 6-30-65 through 7-13-65

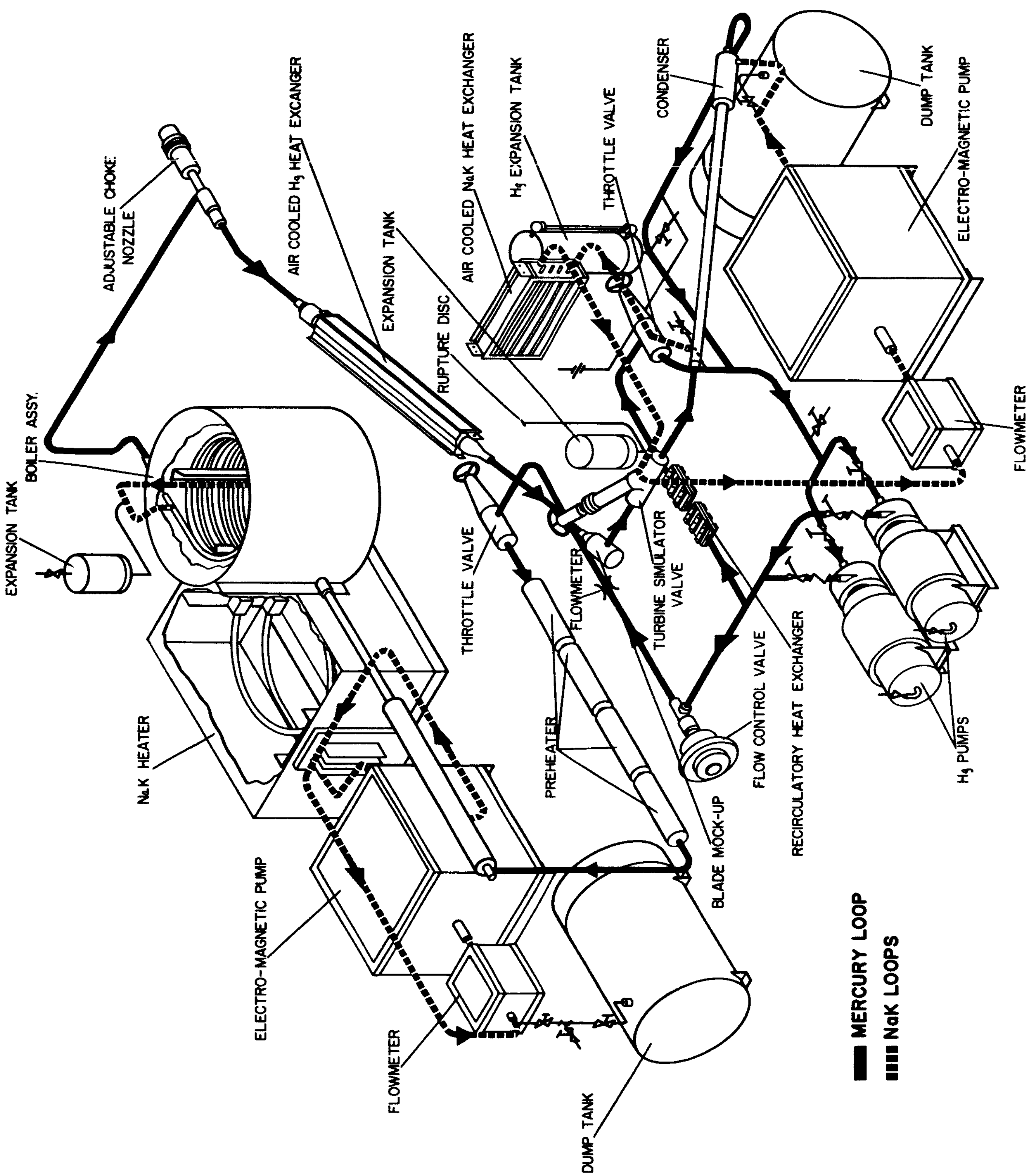
Figure VI-15



Tube-in-Tube Boiler and Cutaway Showing Cross-Counter Flow

566-219

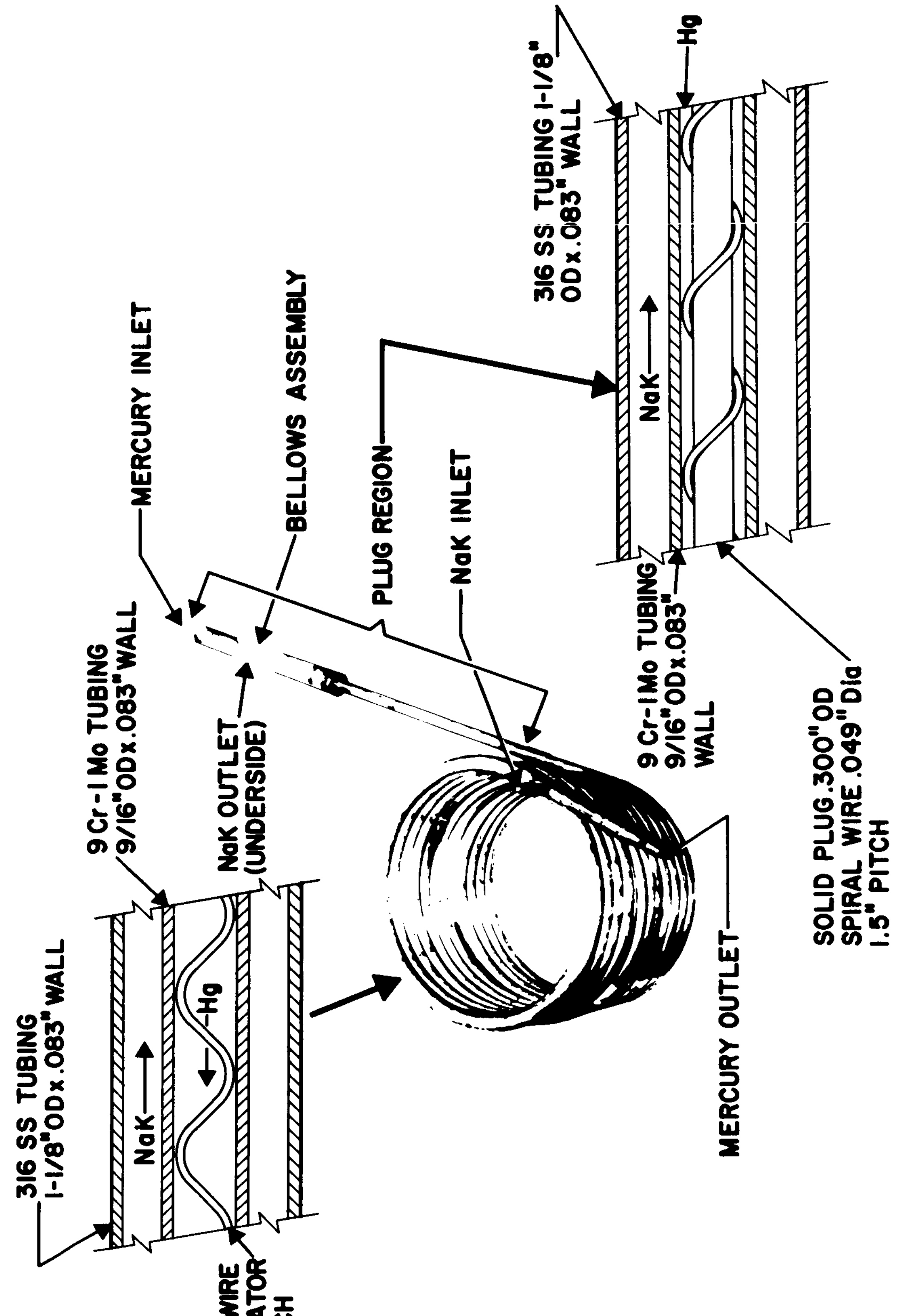
Figure VI-16



Corrosion Loop Layout

1065-455

Figure VI-17



1065-454

Mercury Boiler for MCL-4

Figure VI-18

A366-NF-1128

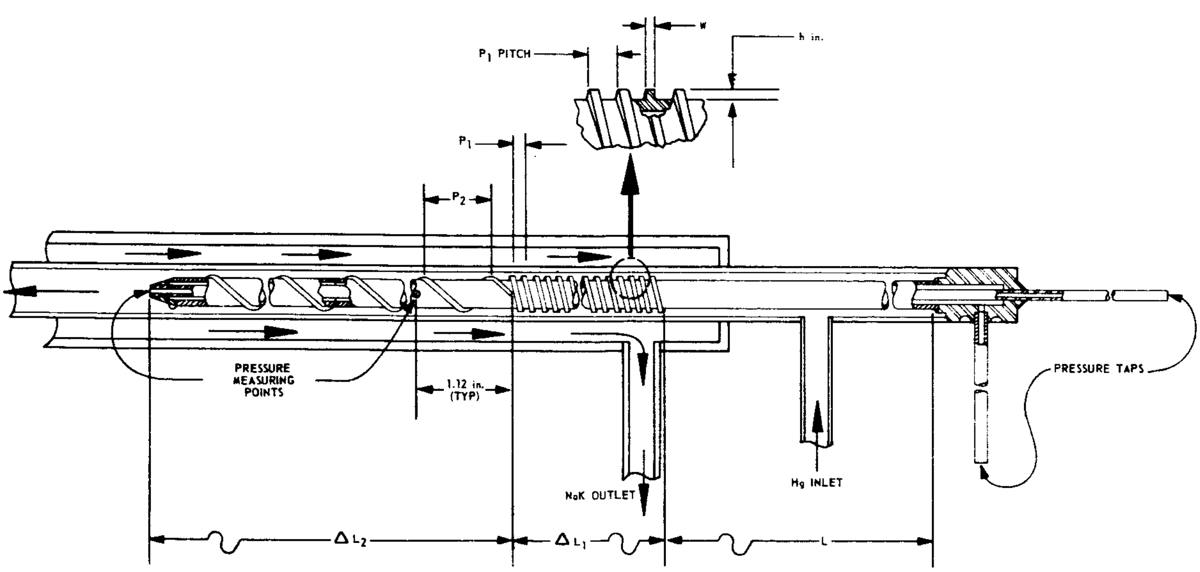
CL-4 BOILER (D X L = 0.400 IN. X 60 FT)

PLUG INSERT GEOMETRIES TESTED

TEST RUN NO.	PLUG INSERT NO.	L	PREHEAT SECTION					VAPOR SECTION				REMARKS
				W	h	P_1	L_1		P_2	L_2		
		IN.	TYPE[1]	IN.	IN.	IN.	IN.	TYPE[1]	IN.	IN.	INSTRUMENTED	
1	1	--	W	--	--	.75	21	W	.75	36	NO	POOR PERFORMANCE DURING FIRST 660 HR
2	2	6	W	--	--	.125	15	W	.75	36	NO	GOOD INITIAL PERFORMANCE
3	2	6	W	--	--	.125	15	W	.75	36	NO	GOOD RESTART PERFORMANCE
4	1	--	W	--	--	.75	21	W	.75	36	NO	GOOD RESTART PERFORMANCE
5	3	9	M	.033	.048	.125	15	W	.75	36	YES	GOOD PERFORMANCE D = .397" (ASSUMED)
6	4	9	M	.038	.045	.125	15	W	1.50	36	YES	GOOD PERFORMANCE D = .400" (ASSUMED)
7	4	9	M	.038	.045	.125	15	W	1.50	36	YES	GOOD PERFORMANCE PLUG #4 REINSERTED
8	3a	9	W	--	--	.125	15	W	1.50	36	YES	GOOD PERFORMANCE
9	3a	9	W	--	--	.125	15	W	1.50	36	YES	GOOD PERFORMANCE P_{ex} AND P_{in} OSCILLATION
10	3b	6	W	--	--	.17	15	W	1.50	24	YES	GOOD PERFORMANCE REDUCED P_{PL}

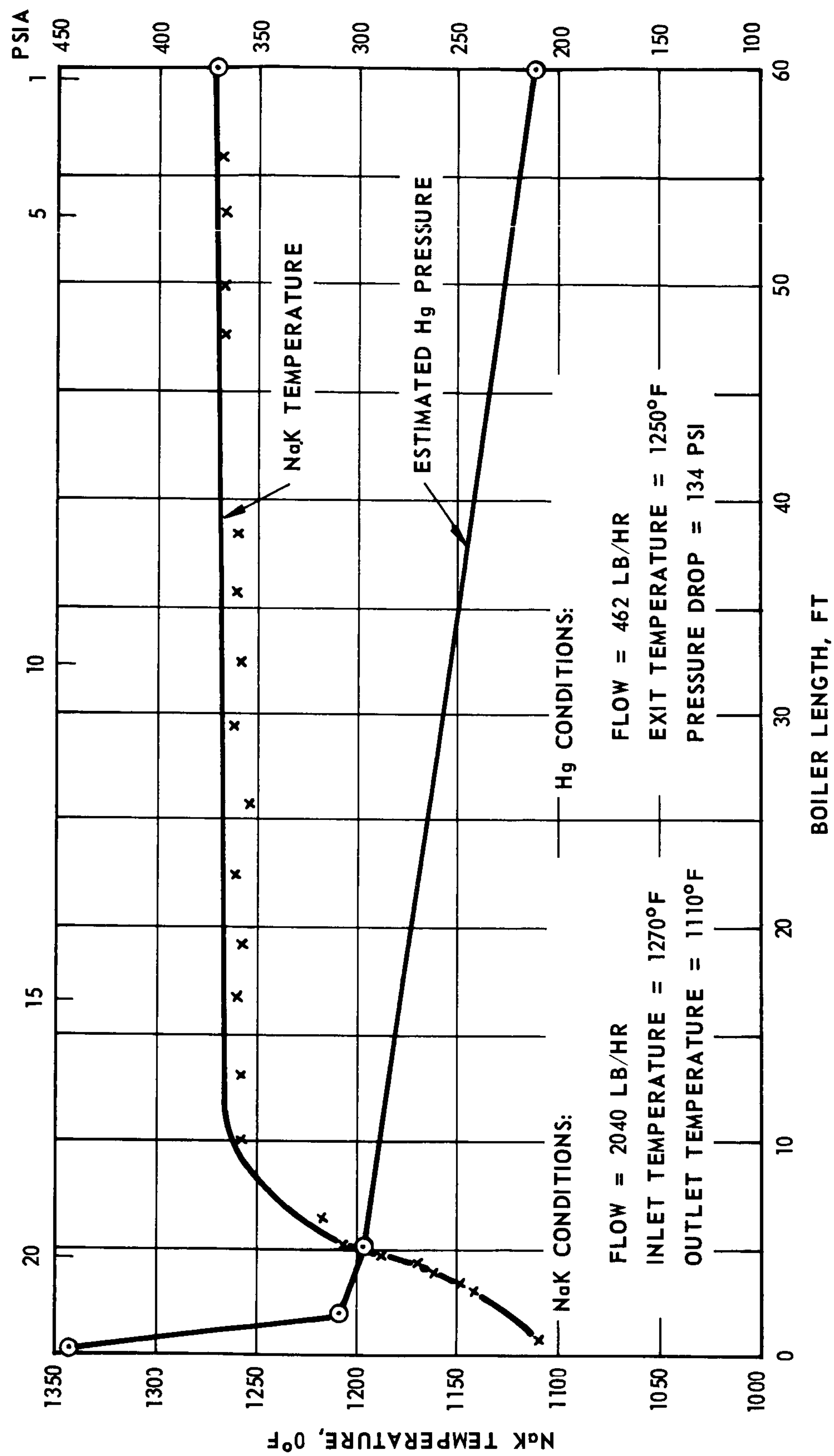
1 M = Machined Thread
W = Wire Wound

NOTES: a. All Wire Uses = 0.049 in. Diameter
b. OD of Plugs = 0.0398 in.



CL-4 Boiler Plug Insert Geometries Tested

Figure VI-19

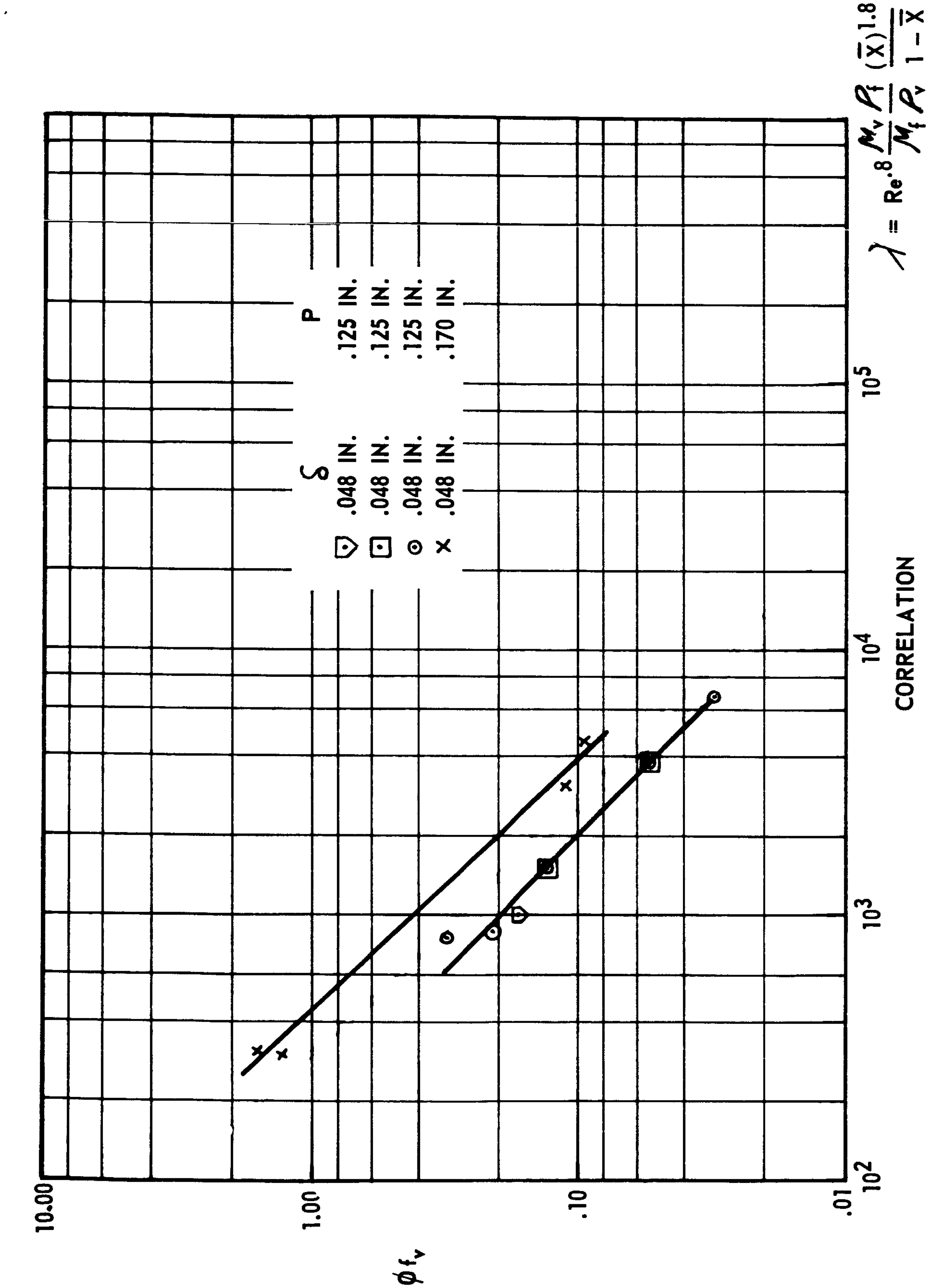


CL-4 Boiler NaK Temperature Profile

A366-NF-1156

Figure VI-20

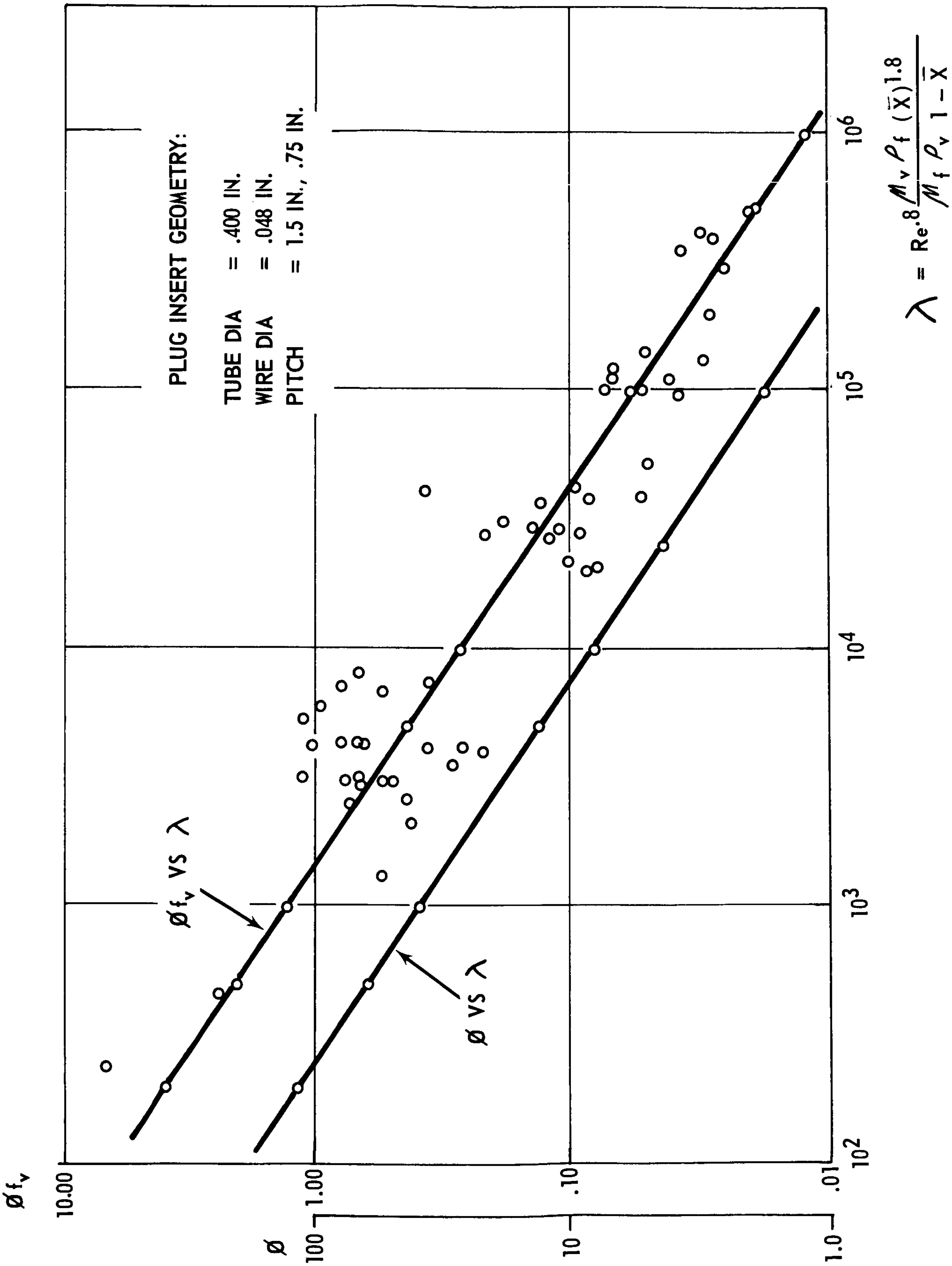
1065-585



Two-Phase Flow Pressure-Drop Correlation in Plug-Insert Preheat Section

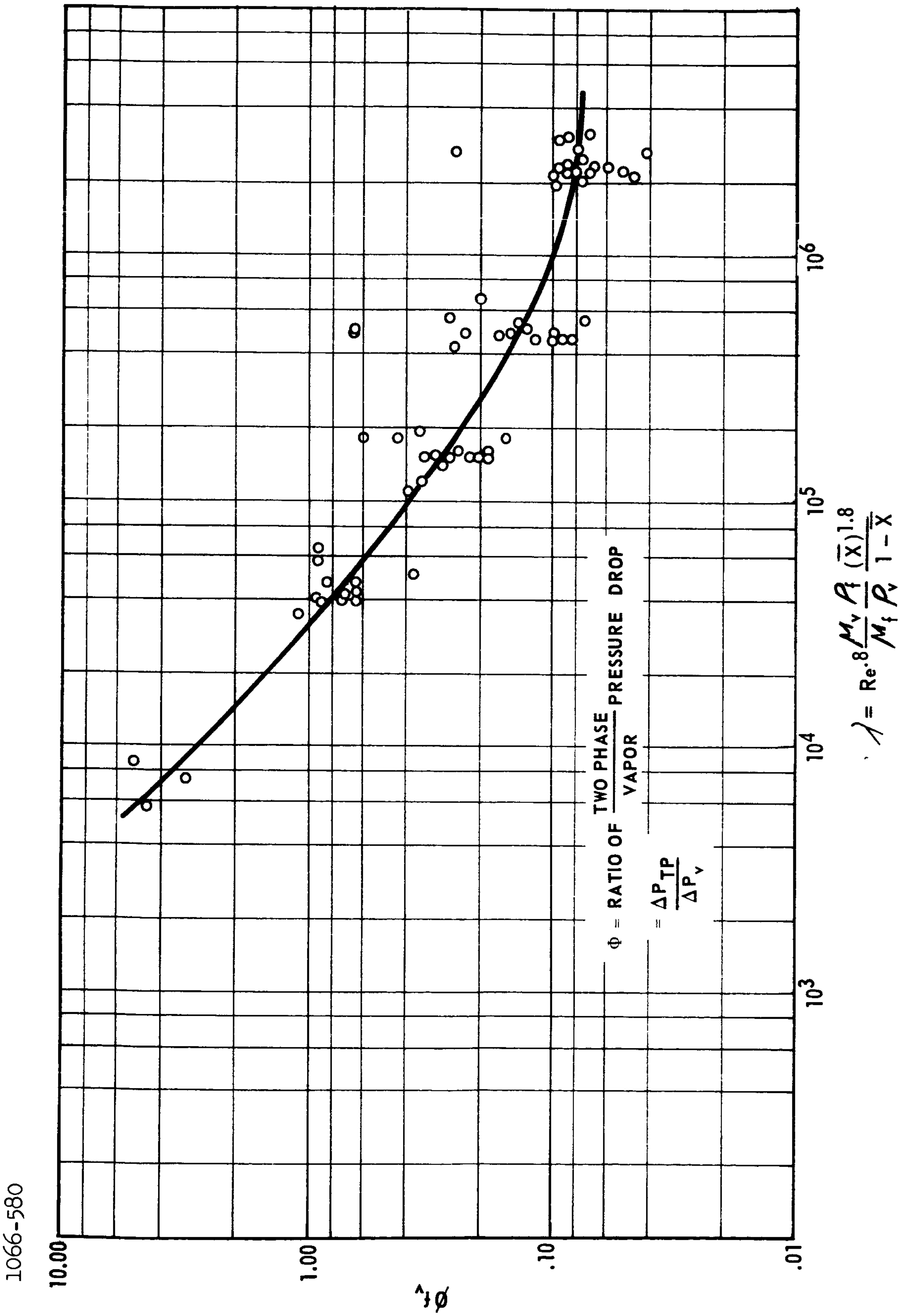
Figure VI-21

1065-582



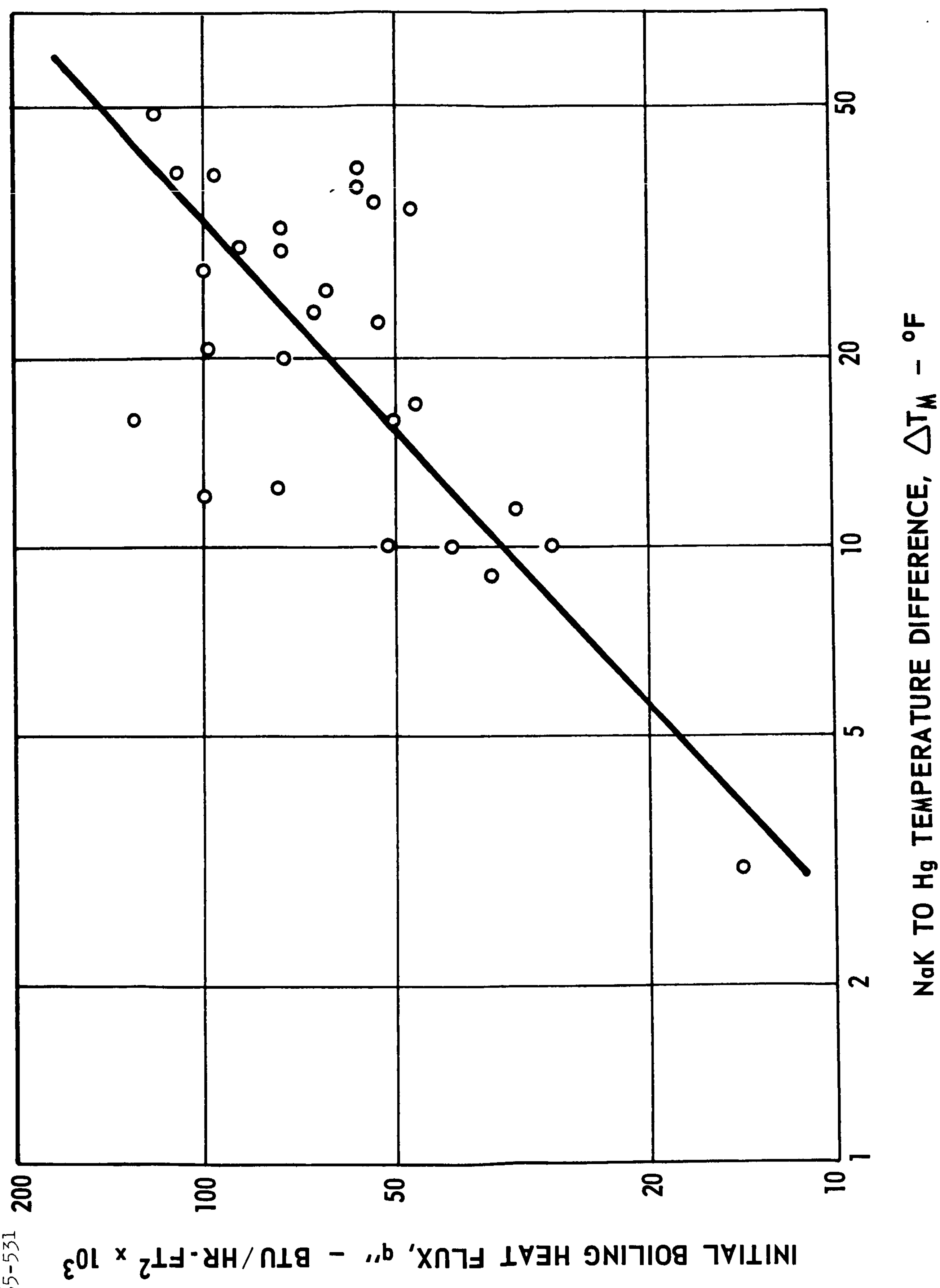
Two-Phase Flow Pressure-Drop Correlation in Plug-Insert Quality Section

Figure VI-22



Two-Phase Flow Pressure-Drop Correlation
Unplugged Tube

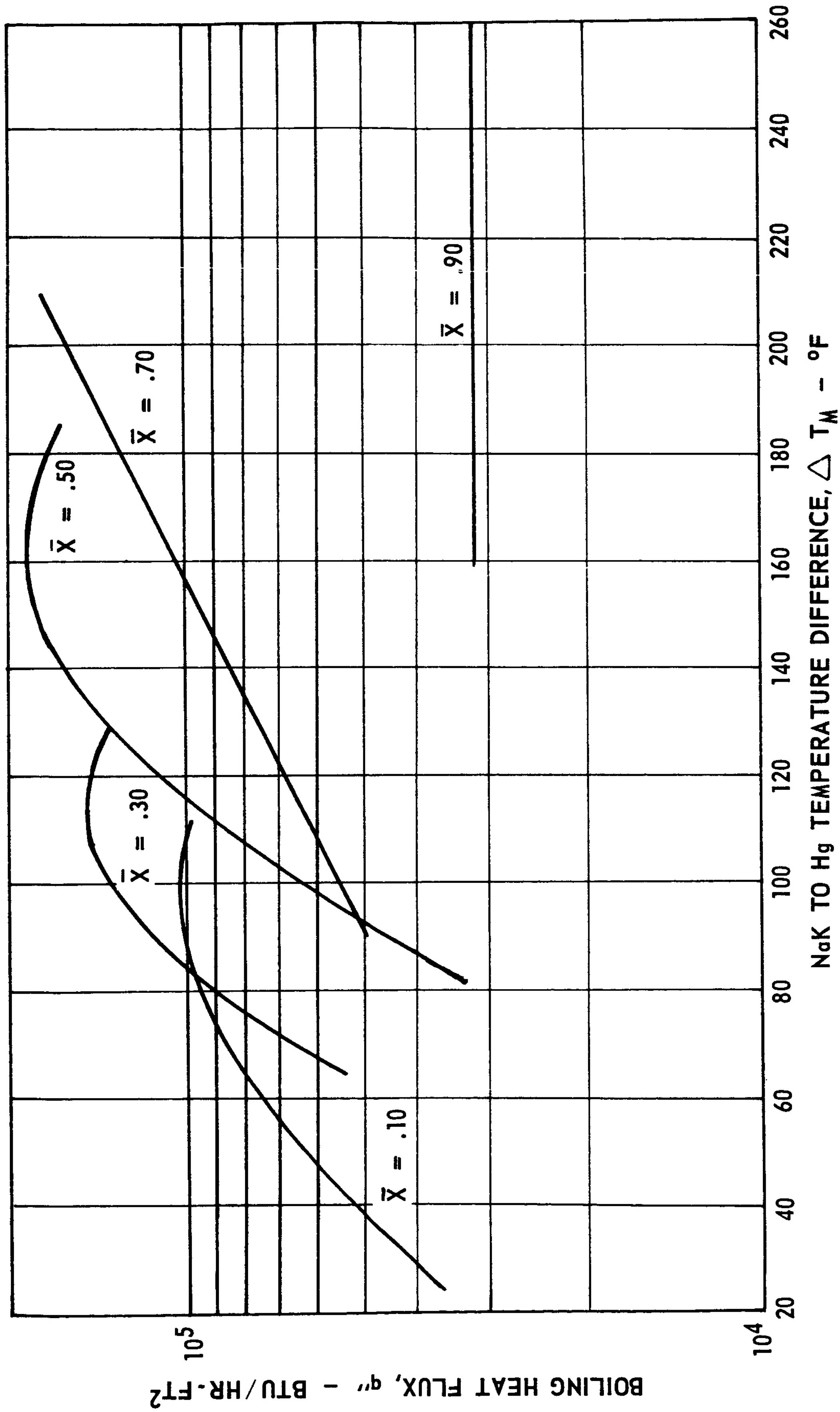
Figure VI-23



Initial Boiling Heat Flux vs NaK-to-Mercury Temperature Difference

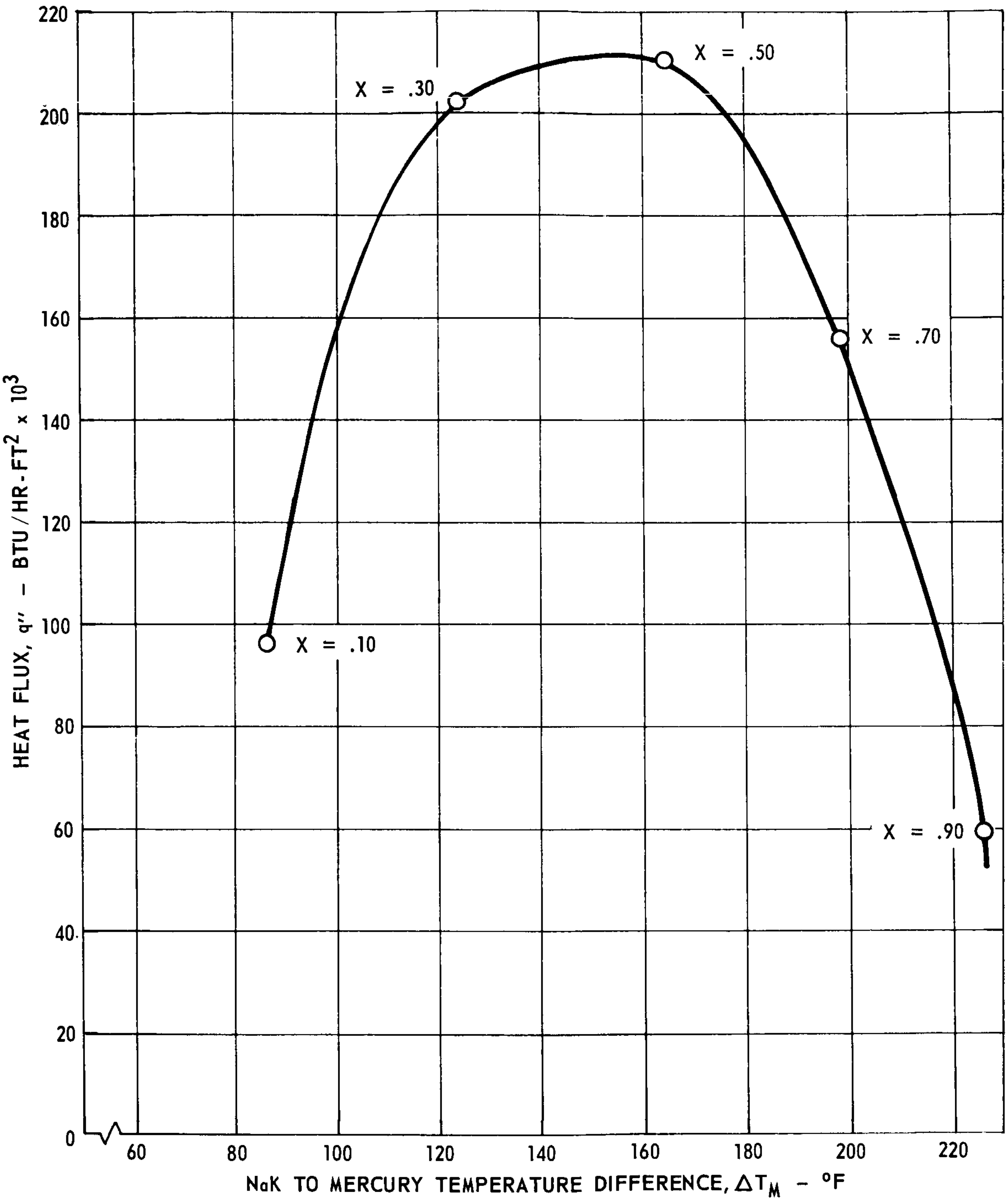
1065-531

Figure VI-24



Boiling Heat Flux with Variation in Mercury Quality

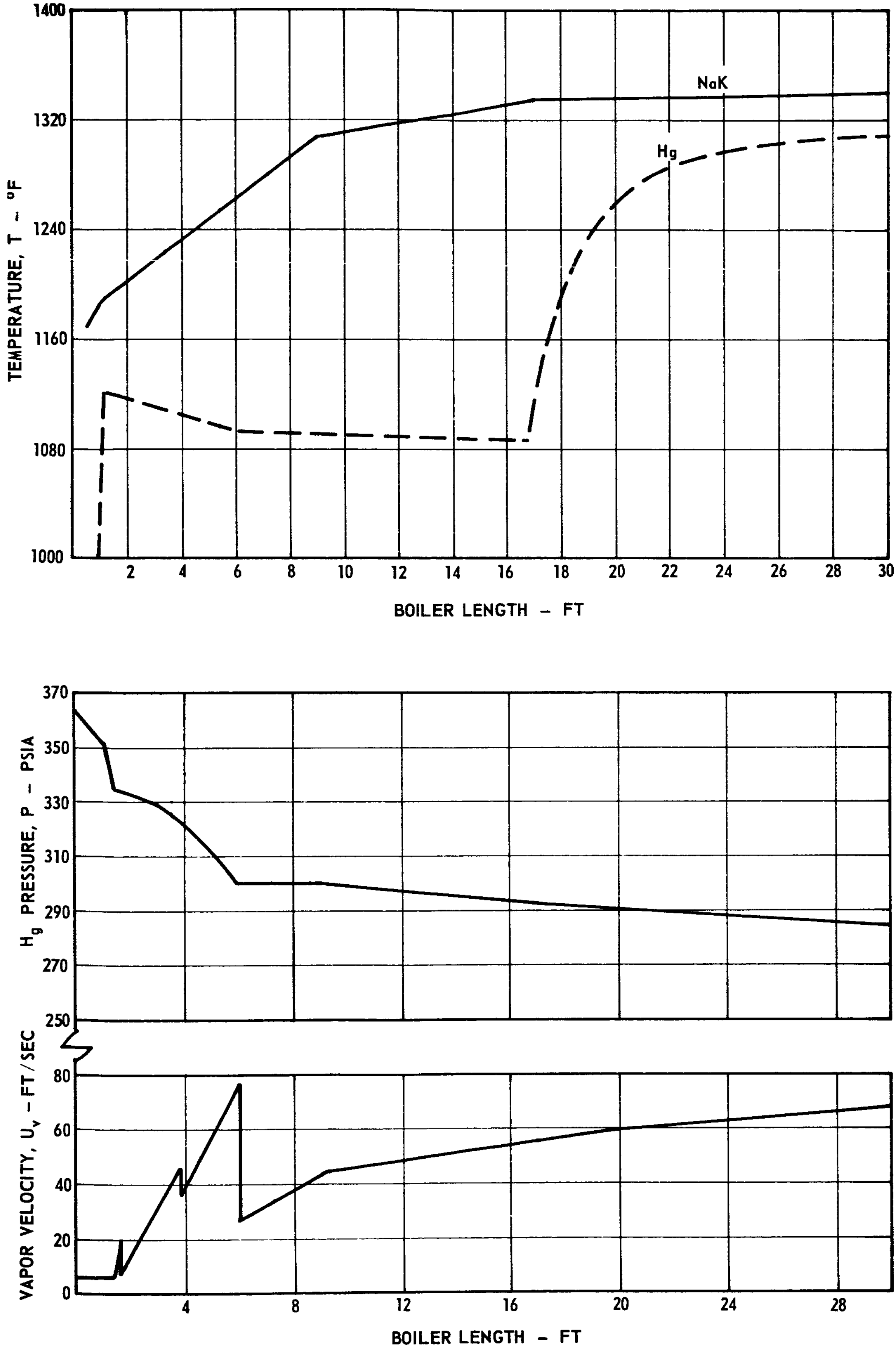
1065-530



1065-570

Typical Boiling Heat Flux Profile

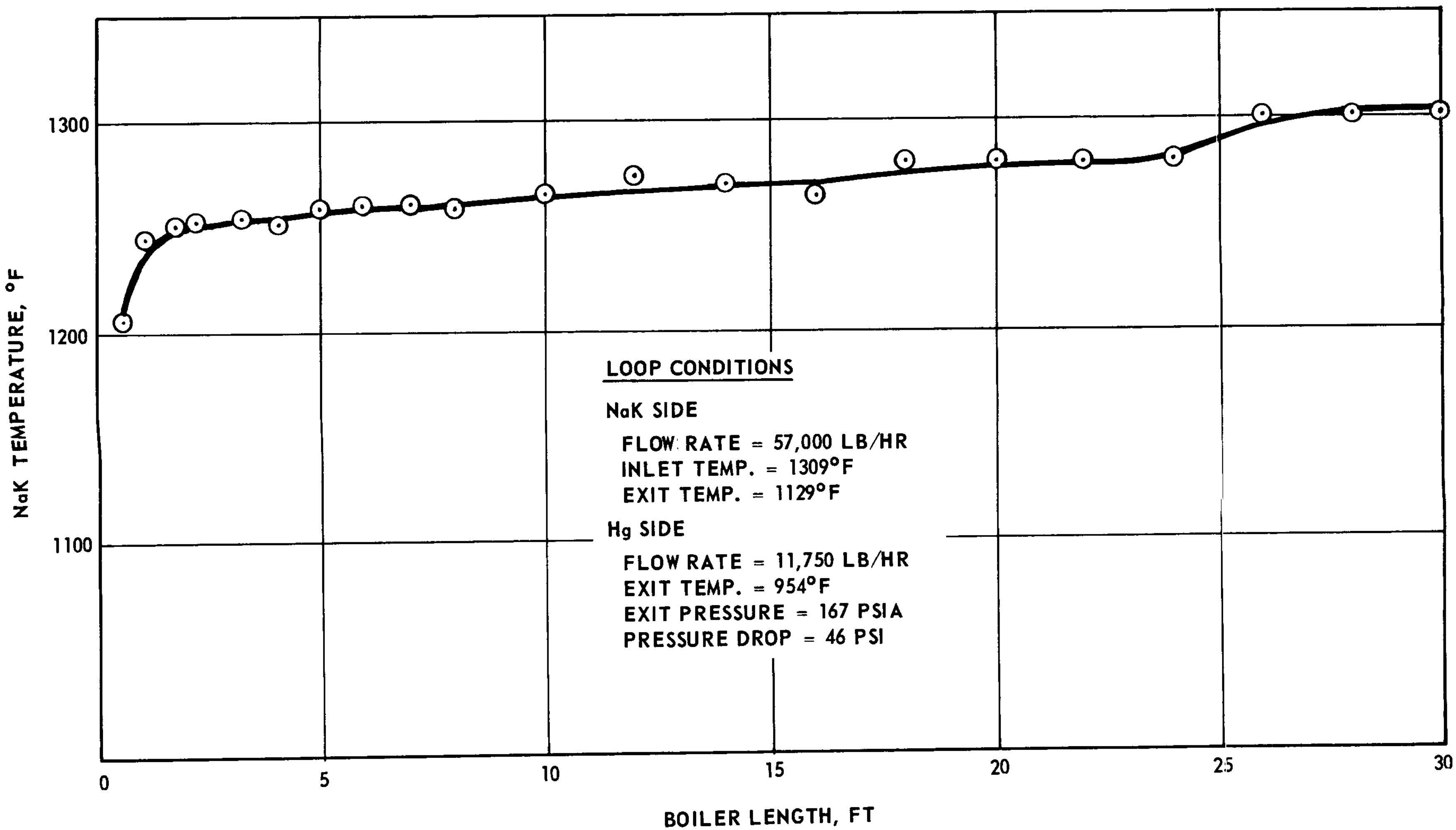
Figure VI-26



Tube-in-Tube Boiler Parameter Profiles

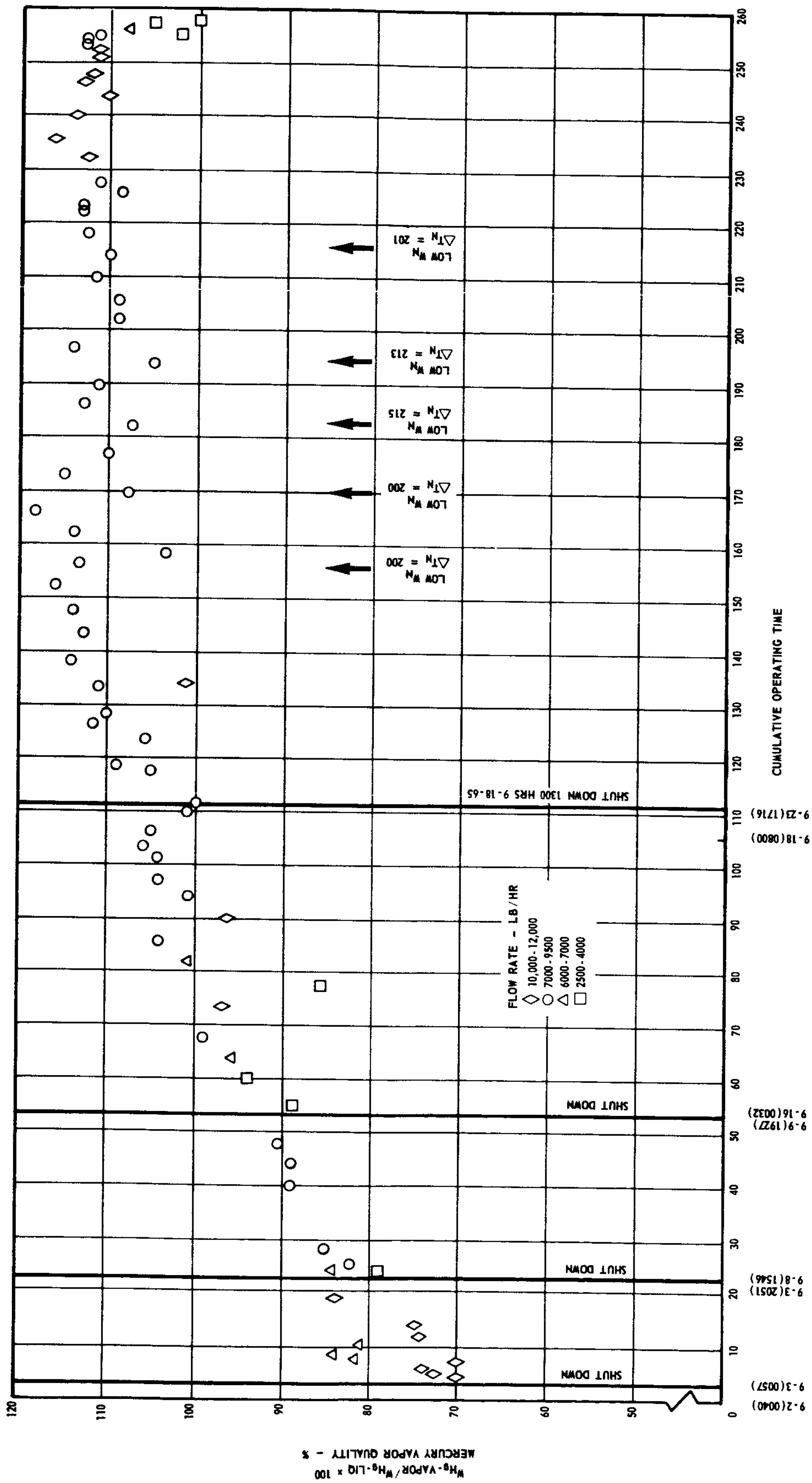
Figure VI-27

A366-NF-1152



Tube-in-Tube Boiler (P/N 097444-5, S/N A-1)
Test in PCS-1, 9-3-65 through 9-29-65 (Data Point 2)
NaK Temperature Profile Showing Deconditioned Performance

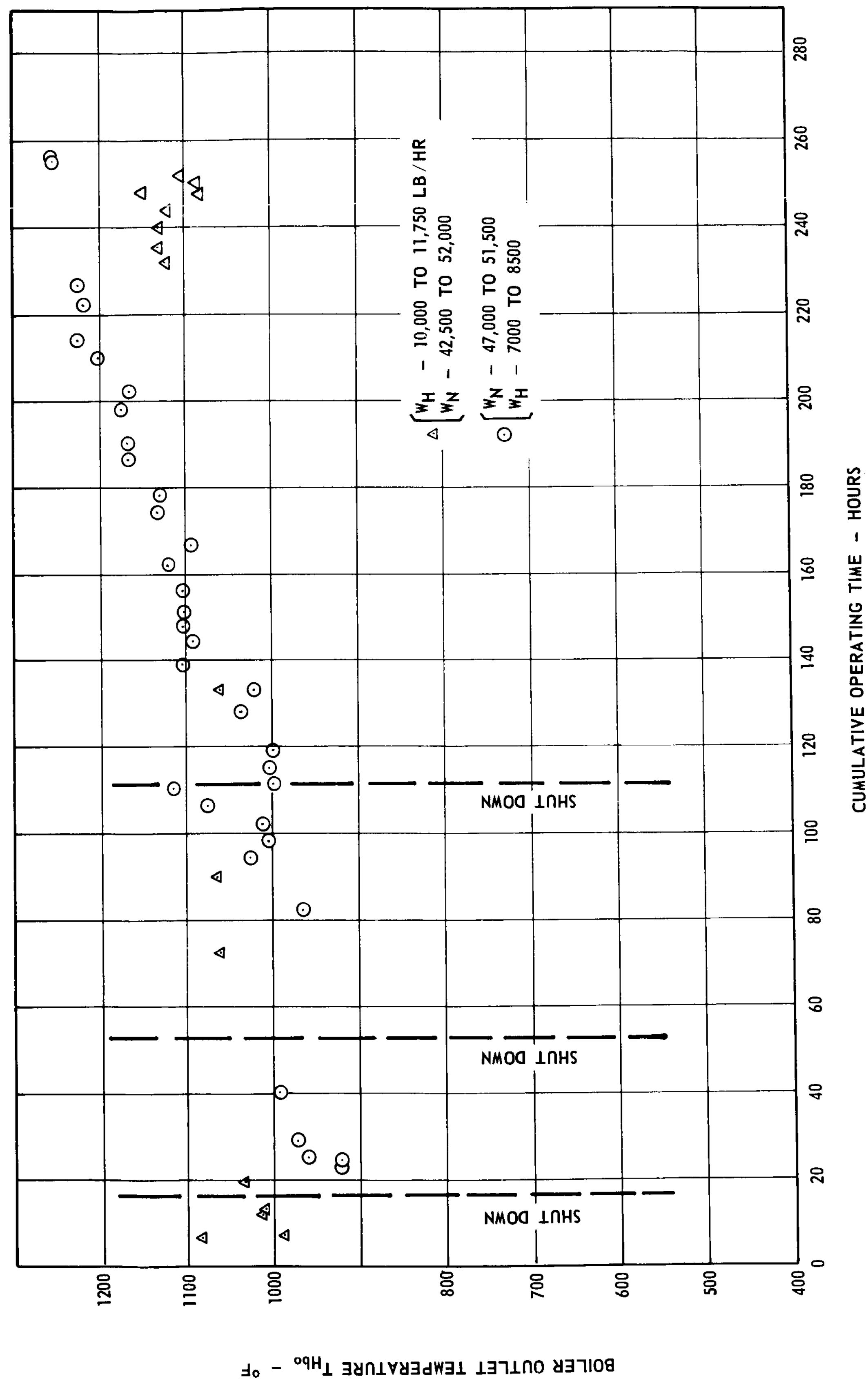
Figure VI-28



Tube-in-Tube Boiler (P/N 097444-5, S/N A-1) Test in PCS-1
9/3/65 through 9/29/65 - Boiler Mercury Vapor Quality With Time

A366-NF-1105

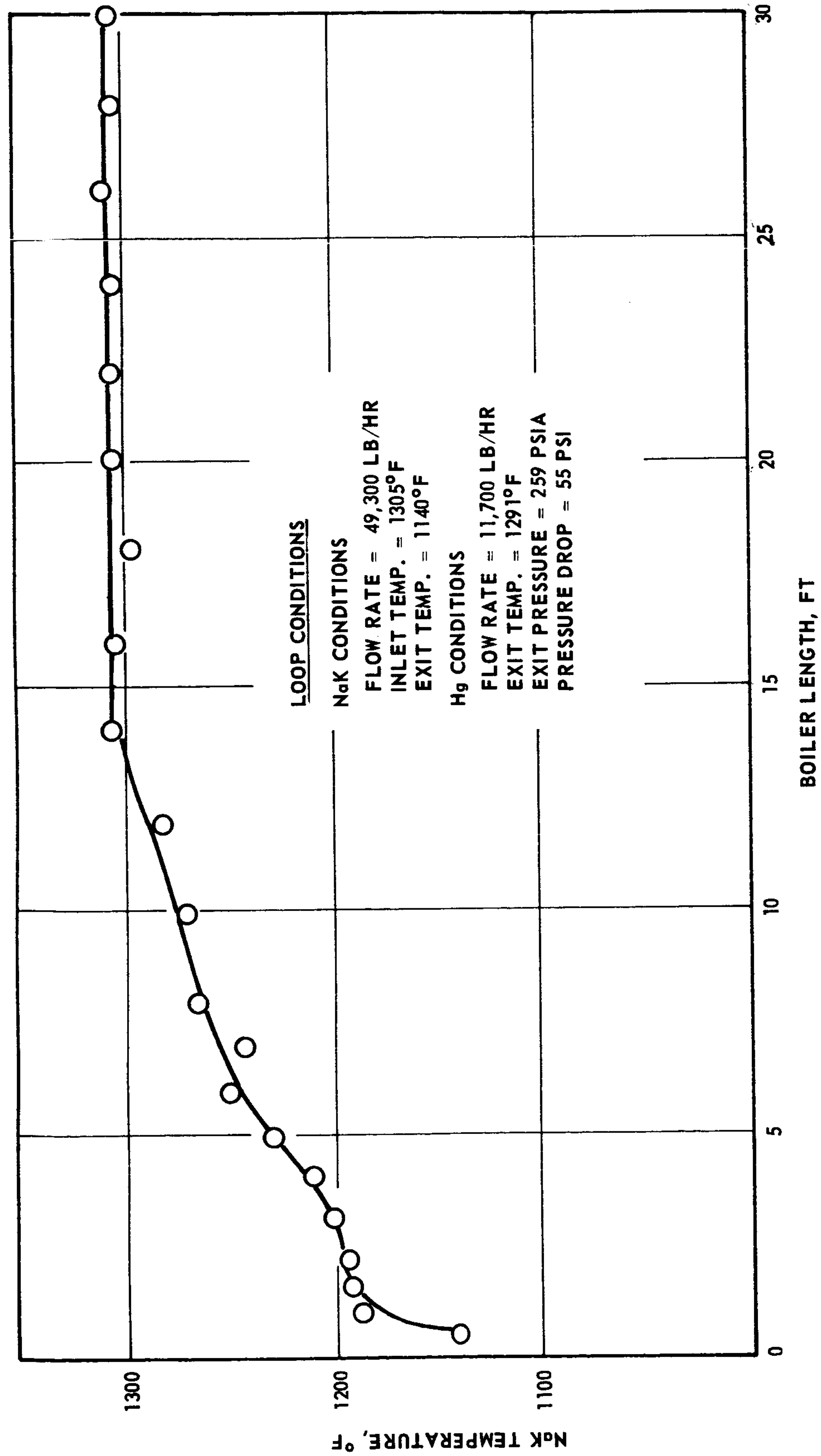
Figure VI-29



Tube-in-Tube Boiler (P/N 097444-5, S/N A-1) Test in PCS-1/SL-1

A366-NF-1110A

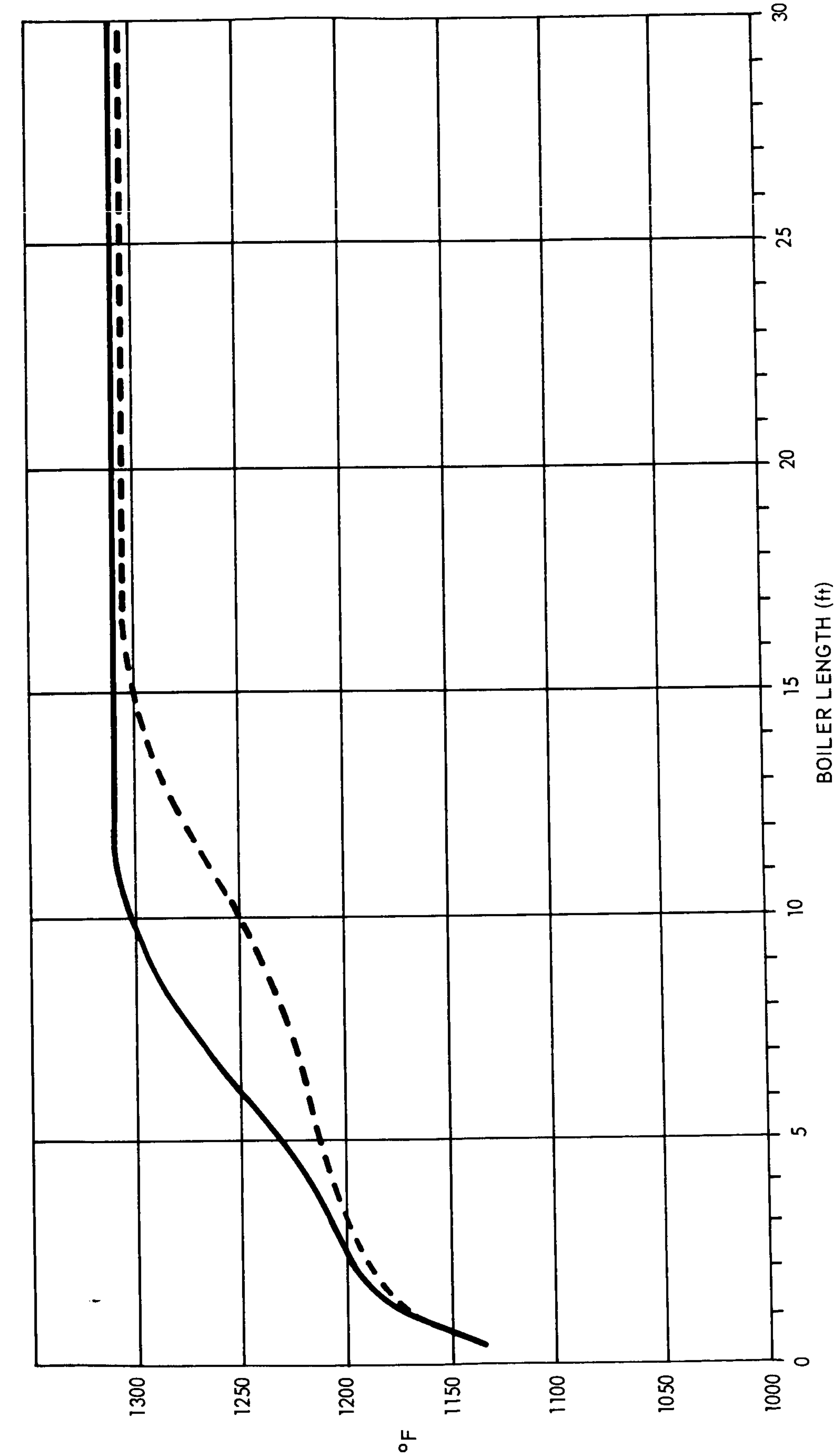
Figure VI-30



Tube-in-Tube Boiler Profile After Conditioning

366-NF-1112A

Figure VI-31

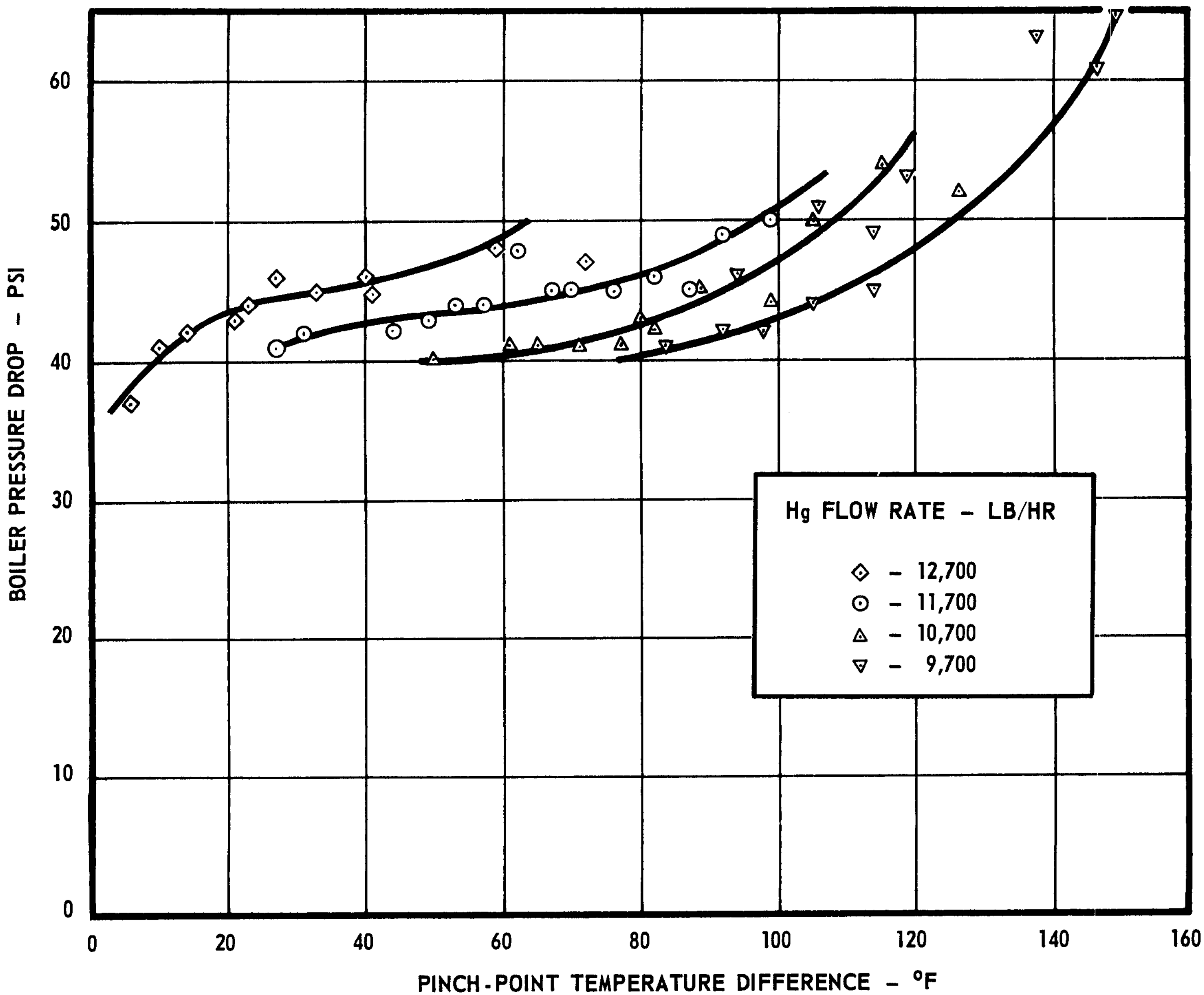


SNAP-8 Tube-in-Tube Boiler (P/N 097444-5, S/N A-1)
NaK Temperature With (Solid Line) and Without (Dashed Line)
the Addition of Rubidium. Based on Tests in PCS-1/SL-1

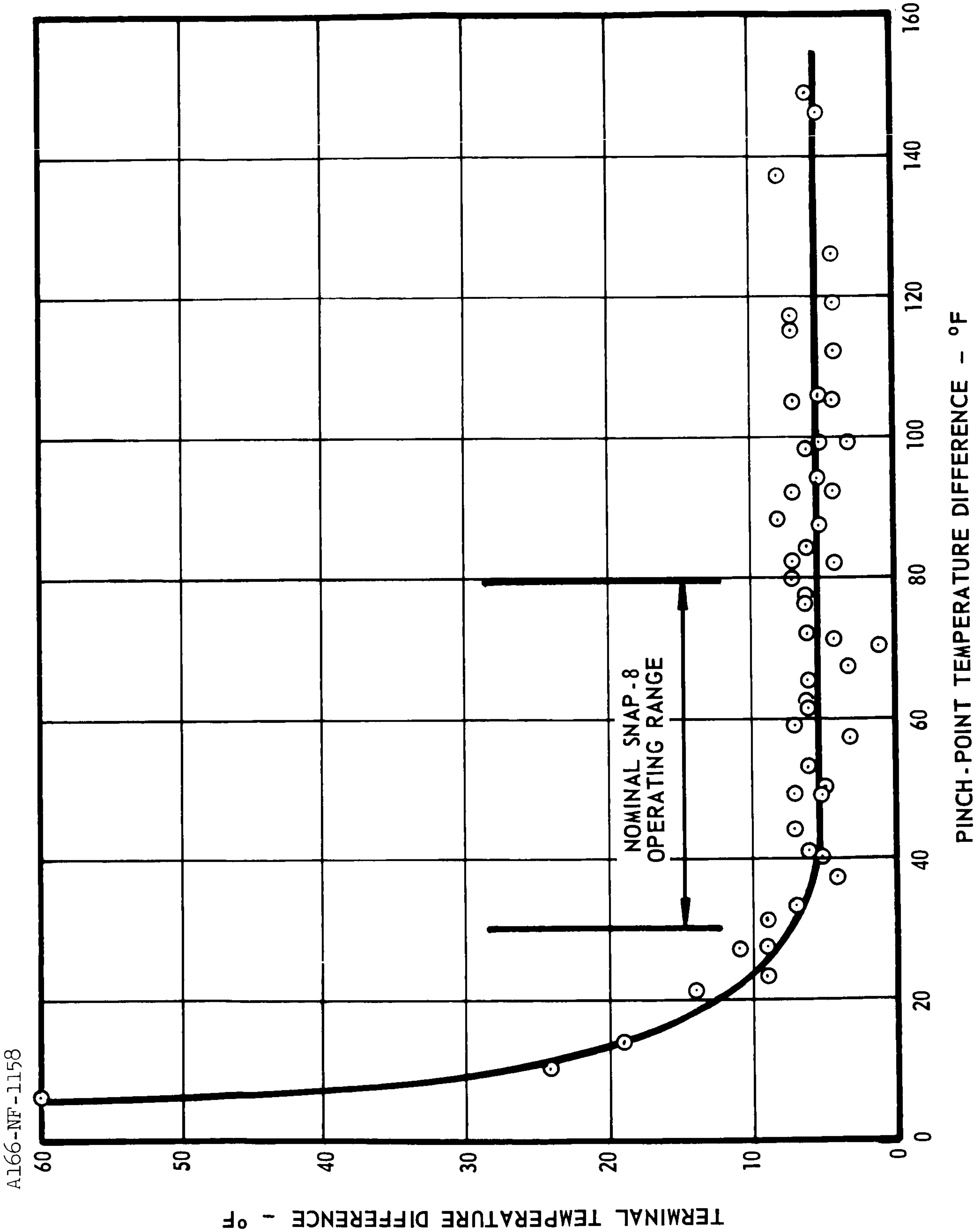
1265-NF-1094

Figure VI-32

A166-NF-1157

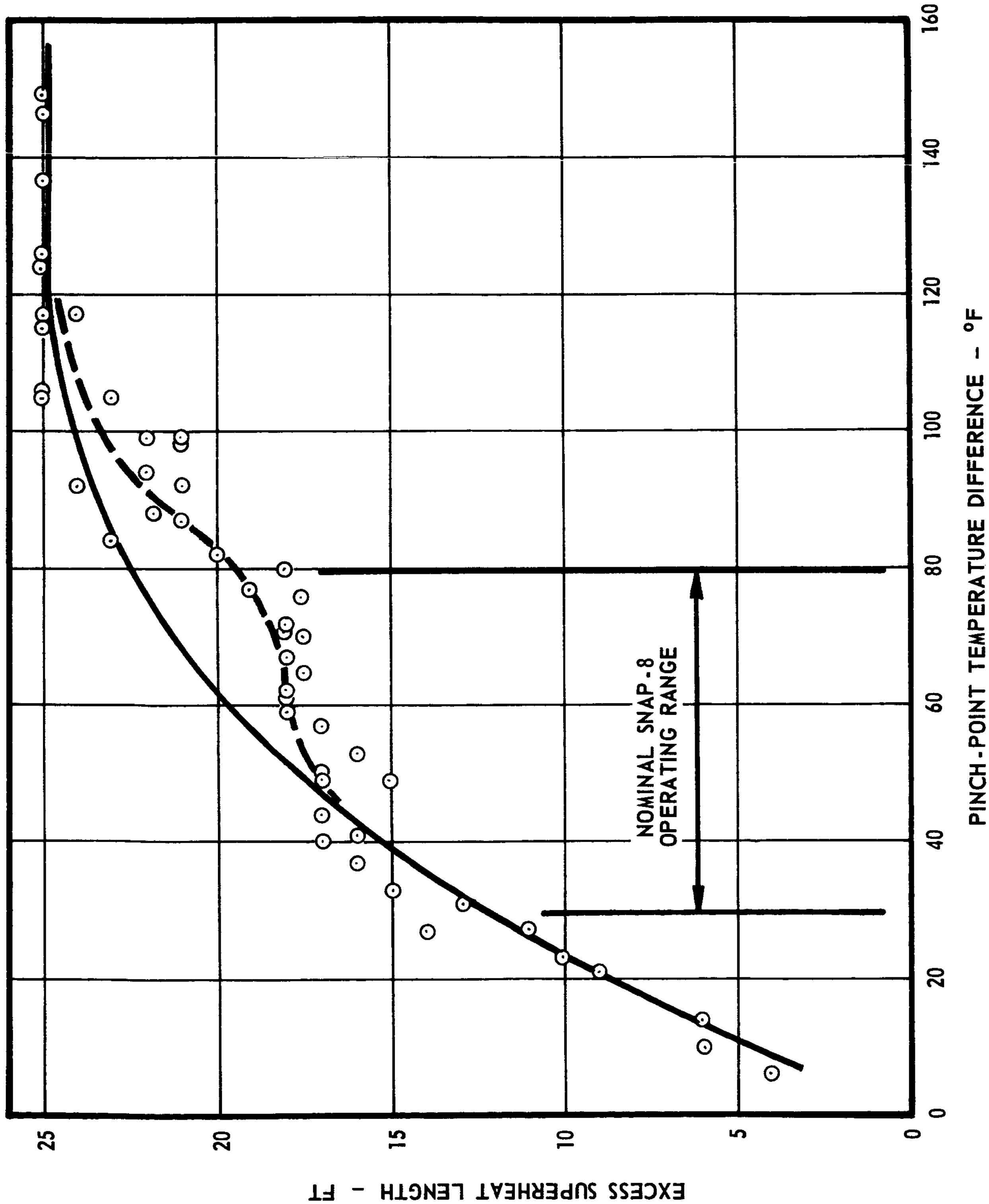


Boiler Pressure Drop - T-T Boiler (P/N 097444-5, S/N A-1)
Tests in PCS-1/SL-1 with Rubidium Added to the Mercury



Terminal Temperature Difference - Tube-in-Tube Boiler (P/N 097444-5, S/N A-1) Tests in PCS-1/SL-1 with Rubidium Added to the Mercury

Figure VI-34

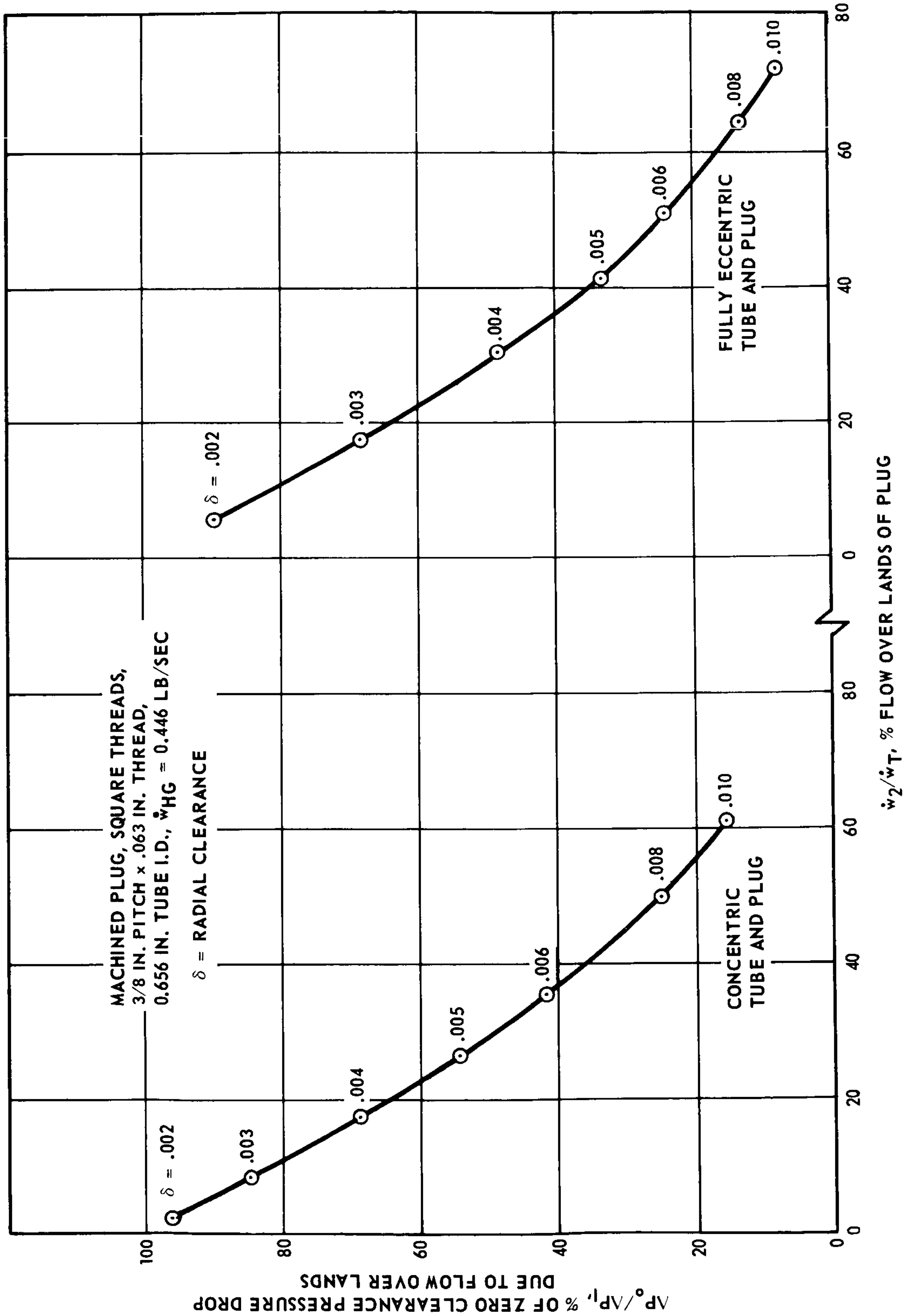


Excess Superheat Length - T-T Boiler (P/N 097444-5, S/N A-1)
Tests in PCS-1/SL-1 with Rubidium Added to the Mercury

A166-NF-1159

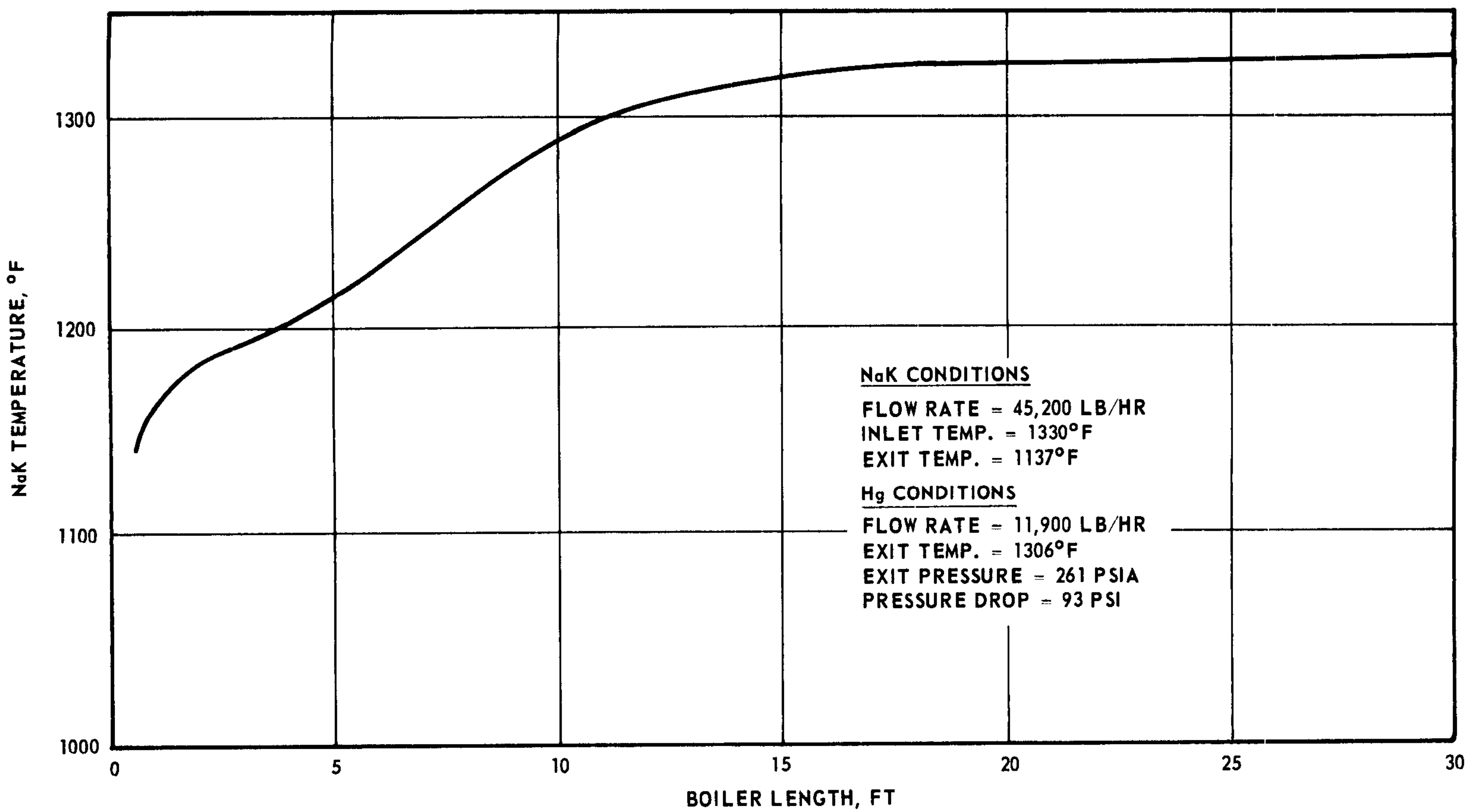
Figure VI-35

A366-NF-1111



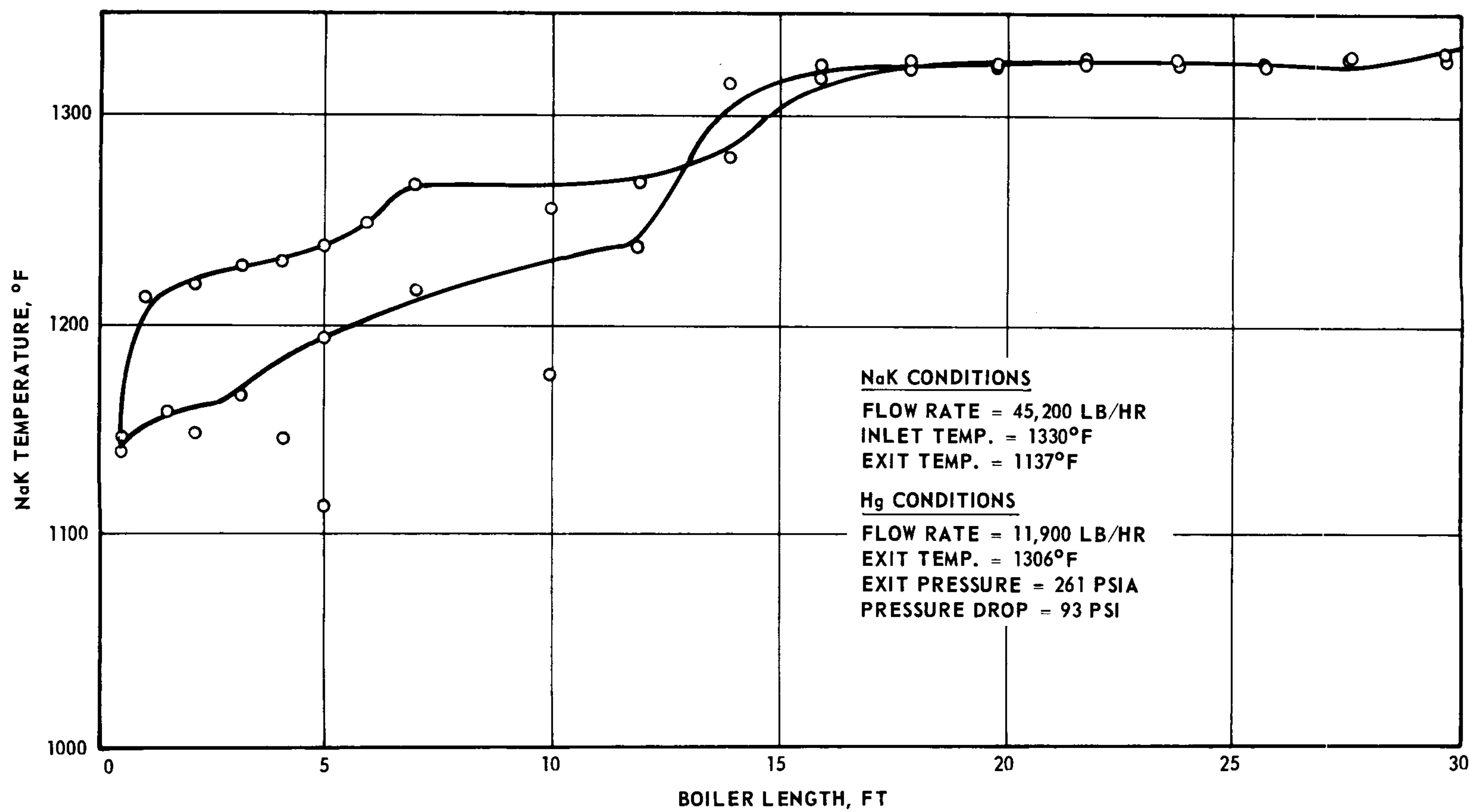
Effect of Clearance and Eccentricity on Plug Pressure Drop, Tube-in-Tube Boiler

A366-NF-1113



Estimated NaK Temperature Profile Showing Conditional Performance During RPL-2 Tests - Run D-3-Z-50, Data Point 16, 12-11-65

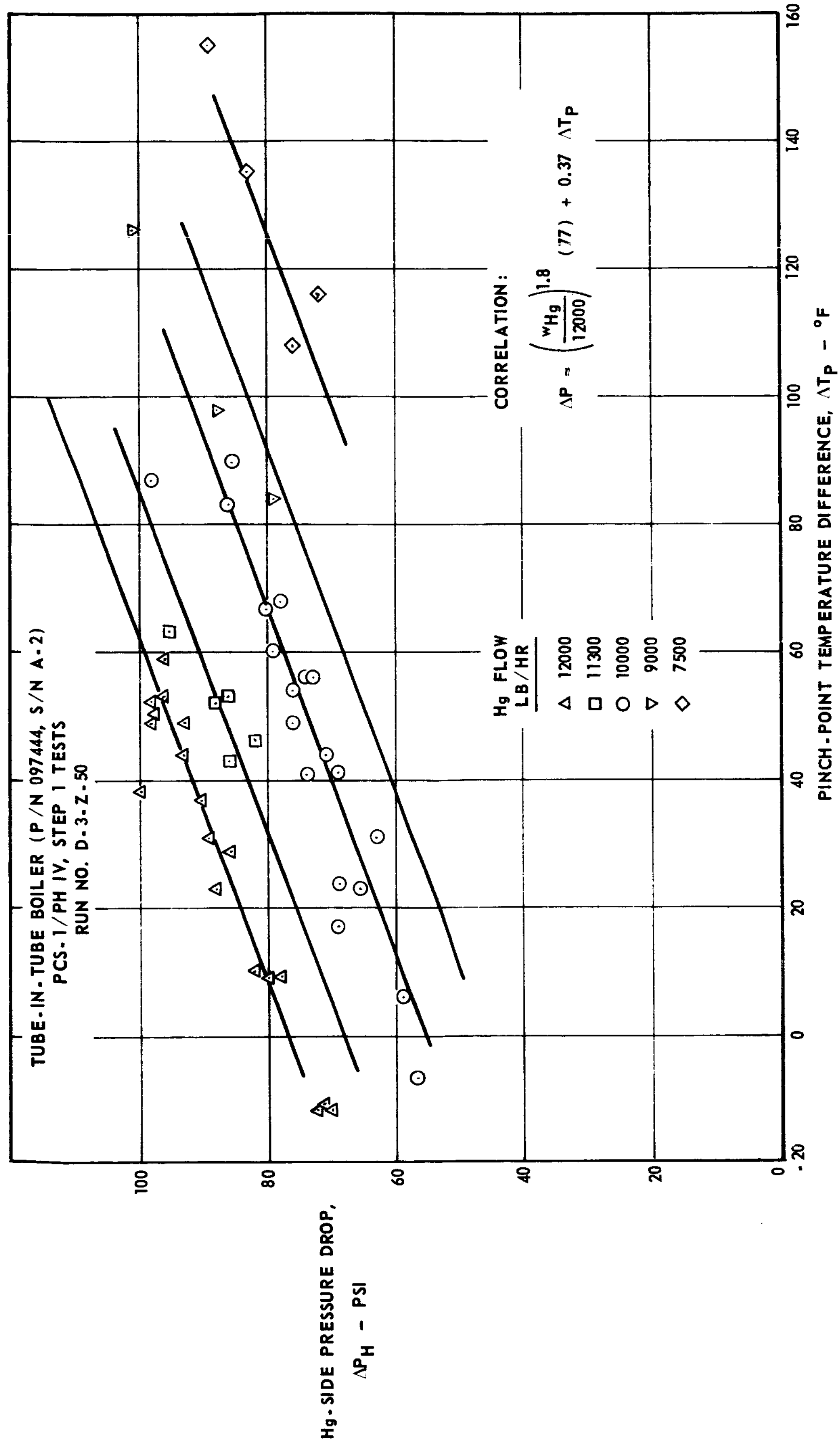
A366-NF-1155



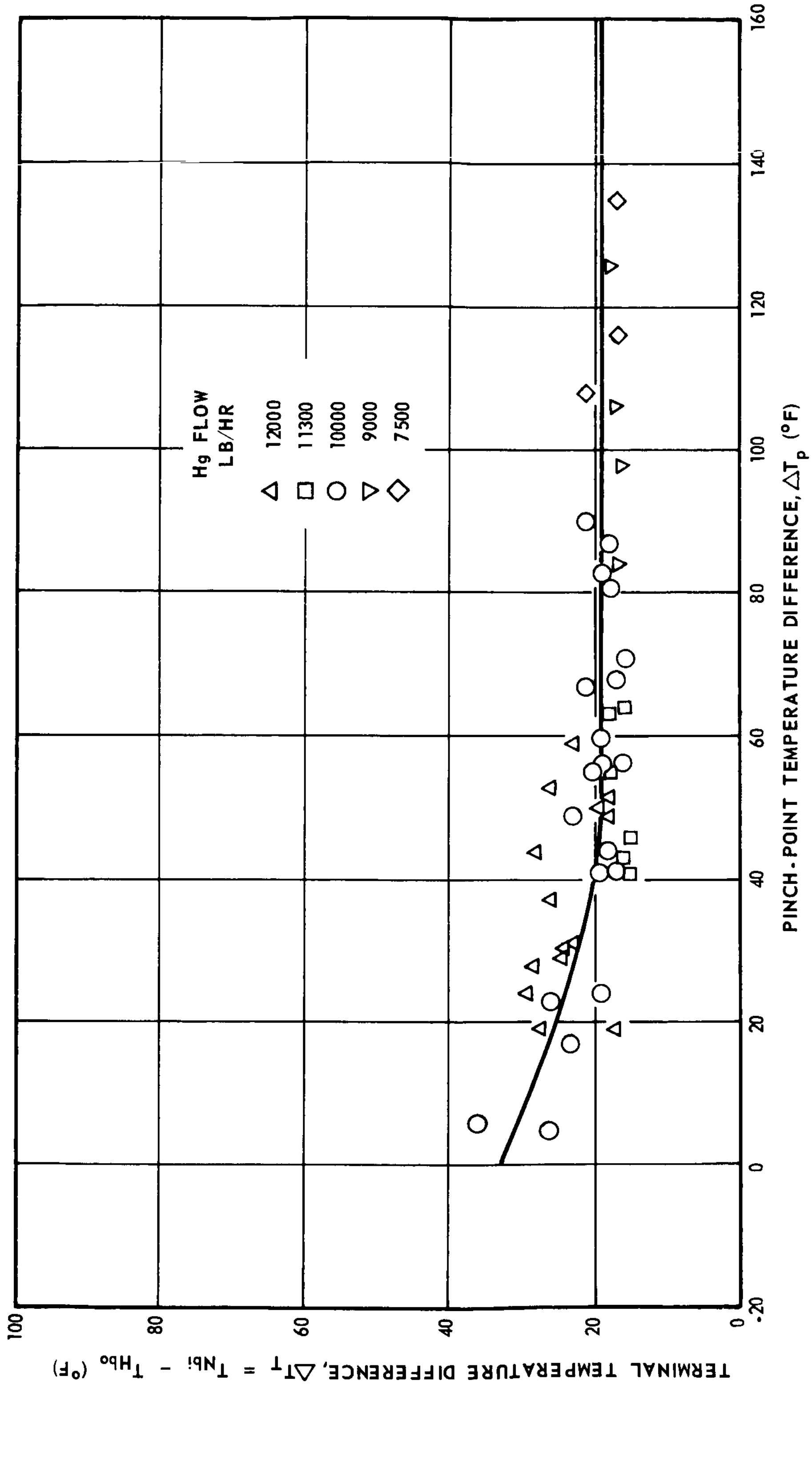
Typical NaK Temperature Profiles Showing Divergence of the Data From the Upper and Lower Thermocouple Locations - Run D-3-Z-50, Data Point 16, 12-11-65

Figure VI-38

A166-NF-1320A



Boiler Pressure Drop with Pinch-Point Temperature Difference

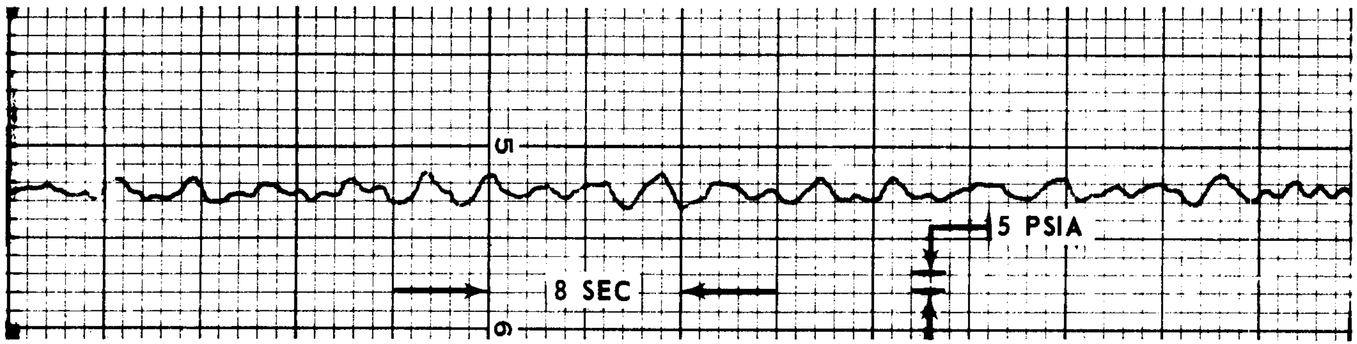


Tube-in-Tube Boiler (P/N 097444-7, S/N A-2) Terminal
Temperature Difference - PCS-1 Phase IV Step 1 Tests
Run No. D-3-A-50

A366-NF-1149

A366-NF-1157A

$$f = 2.7 \ \frac{\text{SEC}}{\text{CYCLE}} \qquad \frac{\sigma_P}{P} = \pm \frac{5}{262.5} = \pm 1.9\%$$



LOOP CONDITIONS:

W_H = 11,750 LB/HR
W_N = 47,000 LB/HR
T_{NBI} = 1329°F
T_{HBO} = 1306°F

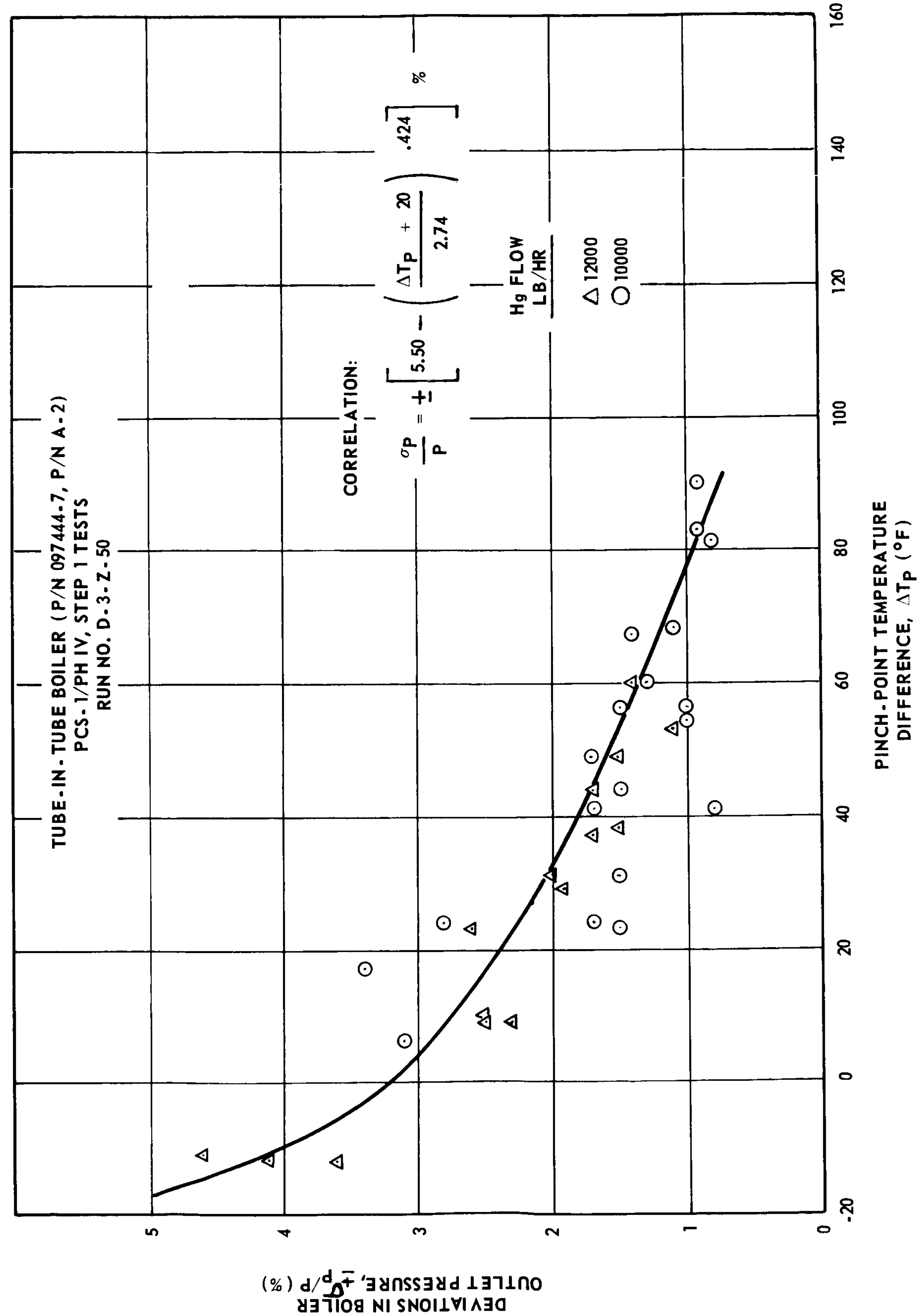
RPL-2 RUN D-3-2-50

DATA PT NO. 20, 1254/1259 HR, 12-11-65

Boiler Outlet Pressure Strip Chart Record

Figure VI-41

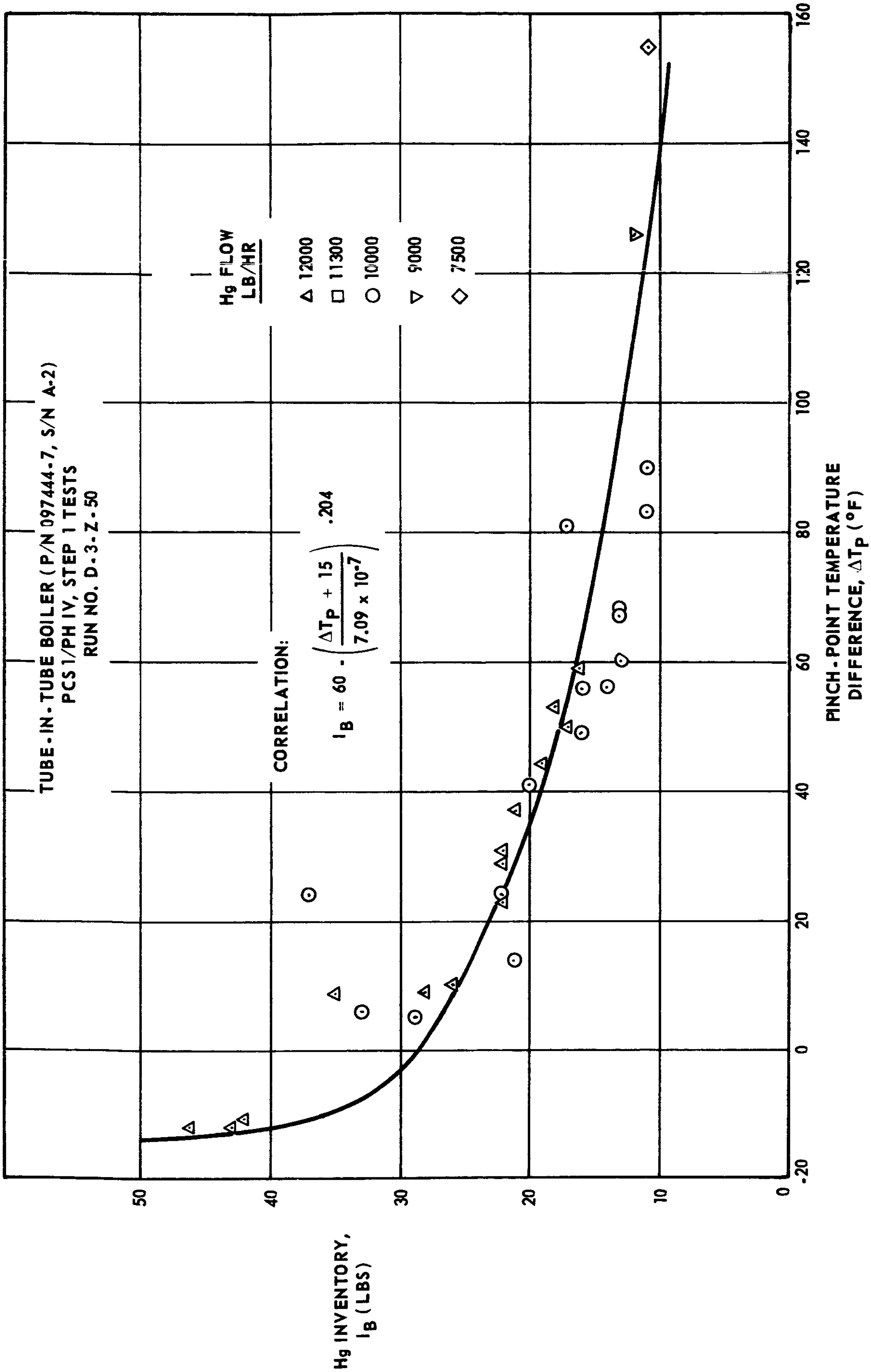
166-NF-1321A



Boiler Outlet Pressure Fluctuations

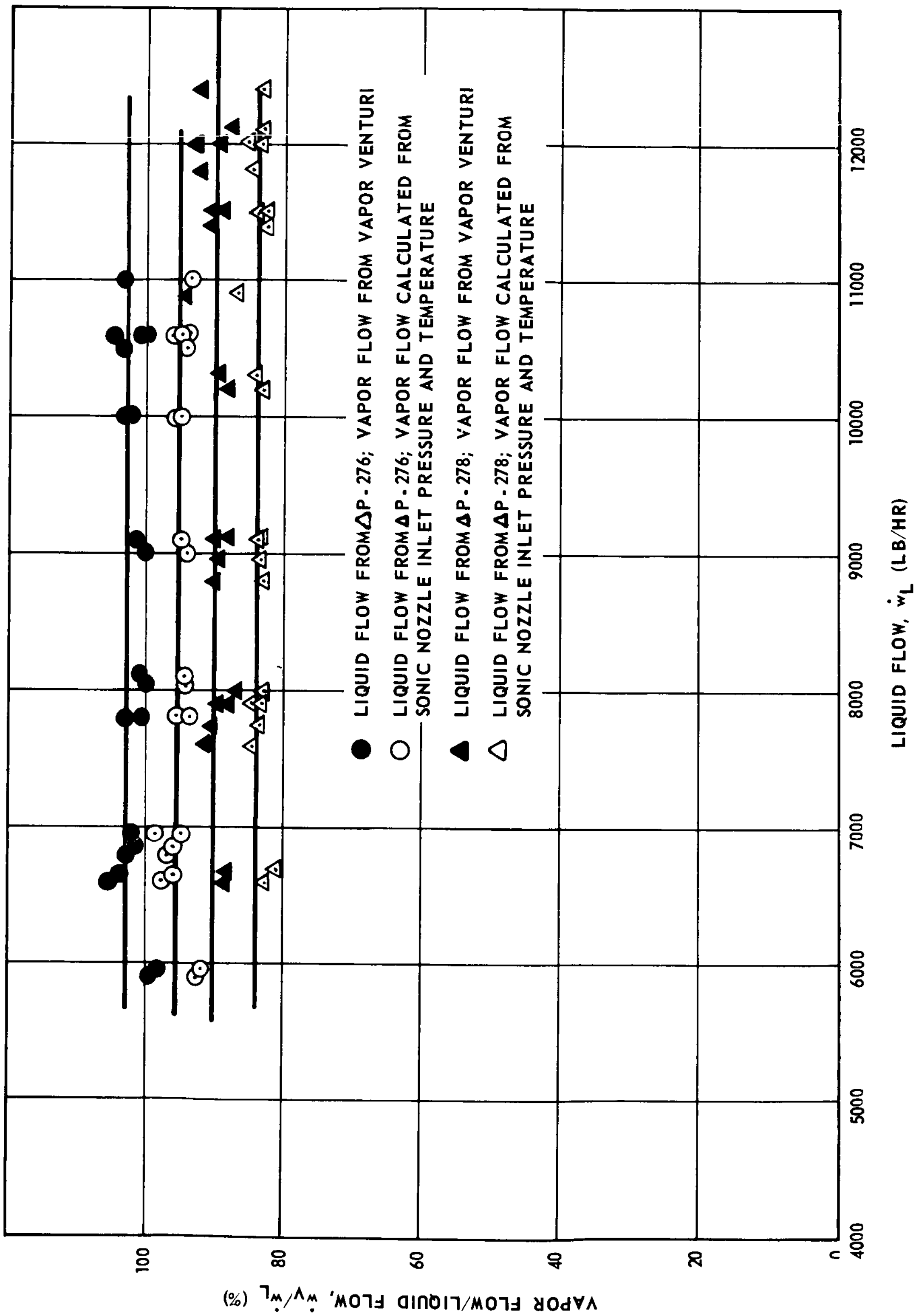
Figure VI-42

166-NF-1322A



Boiler Hg Inventory with Pinch-Point Temperature Difference

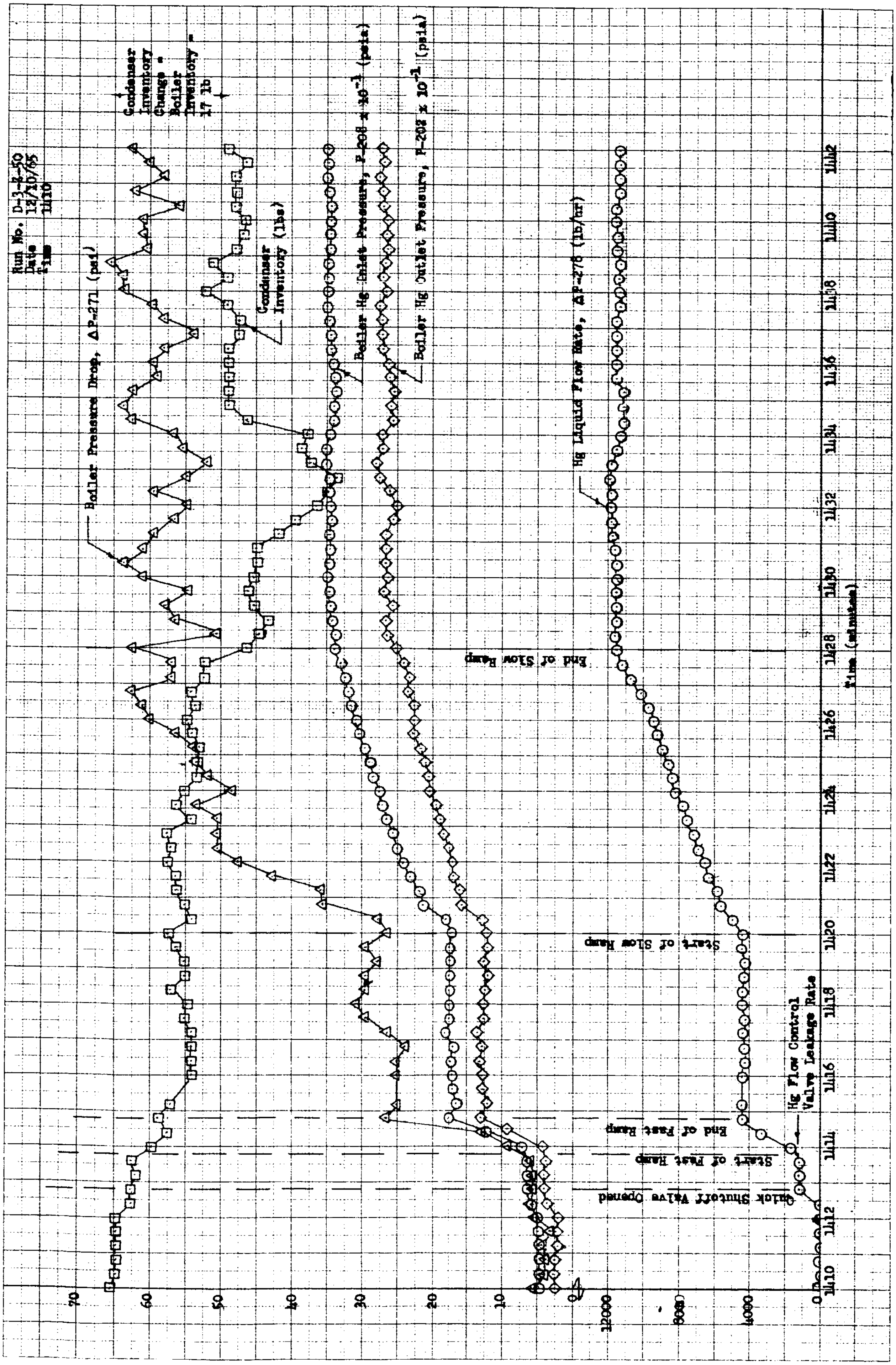
Figure VI-43



Tube-in-Tube Boiler (P/N 097444-7, S/N A-2) Exit Quality with Flow Rate - Test Series D-3-A-50, PCS-1 Phase IV Step 1

A366-NF-1150

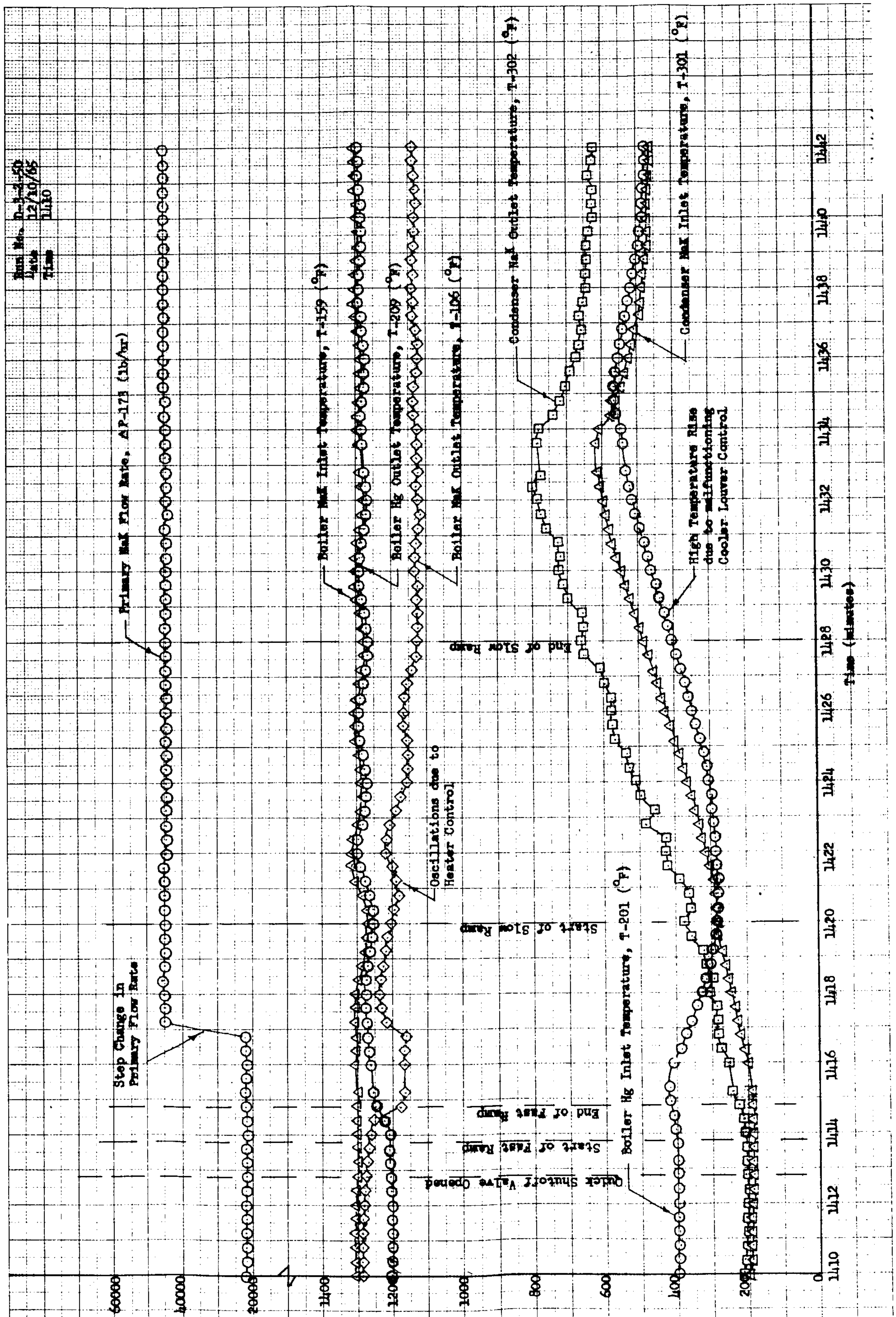
Figure VI-44



Boiler Transient Showing Mercury Side Response to Simulated Injection Startup No. 1

A166-NF-1148

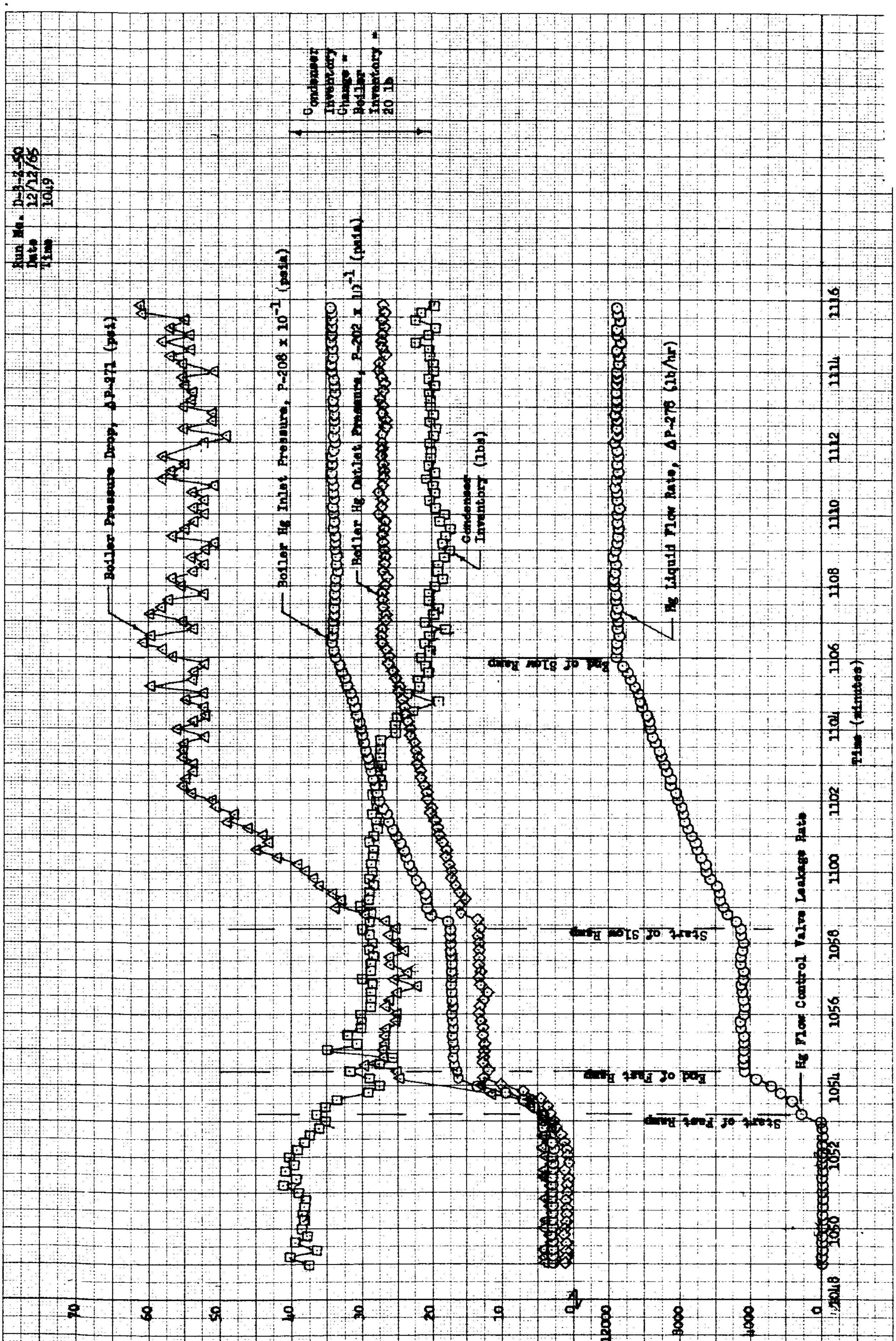
Figure VI-45



Boiler Transient Showing NaK Side Response to Simulated Injection Startup No. 1

B166-NF-1149

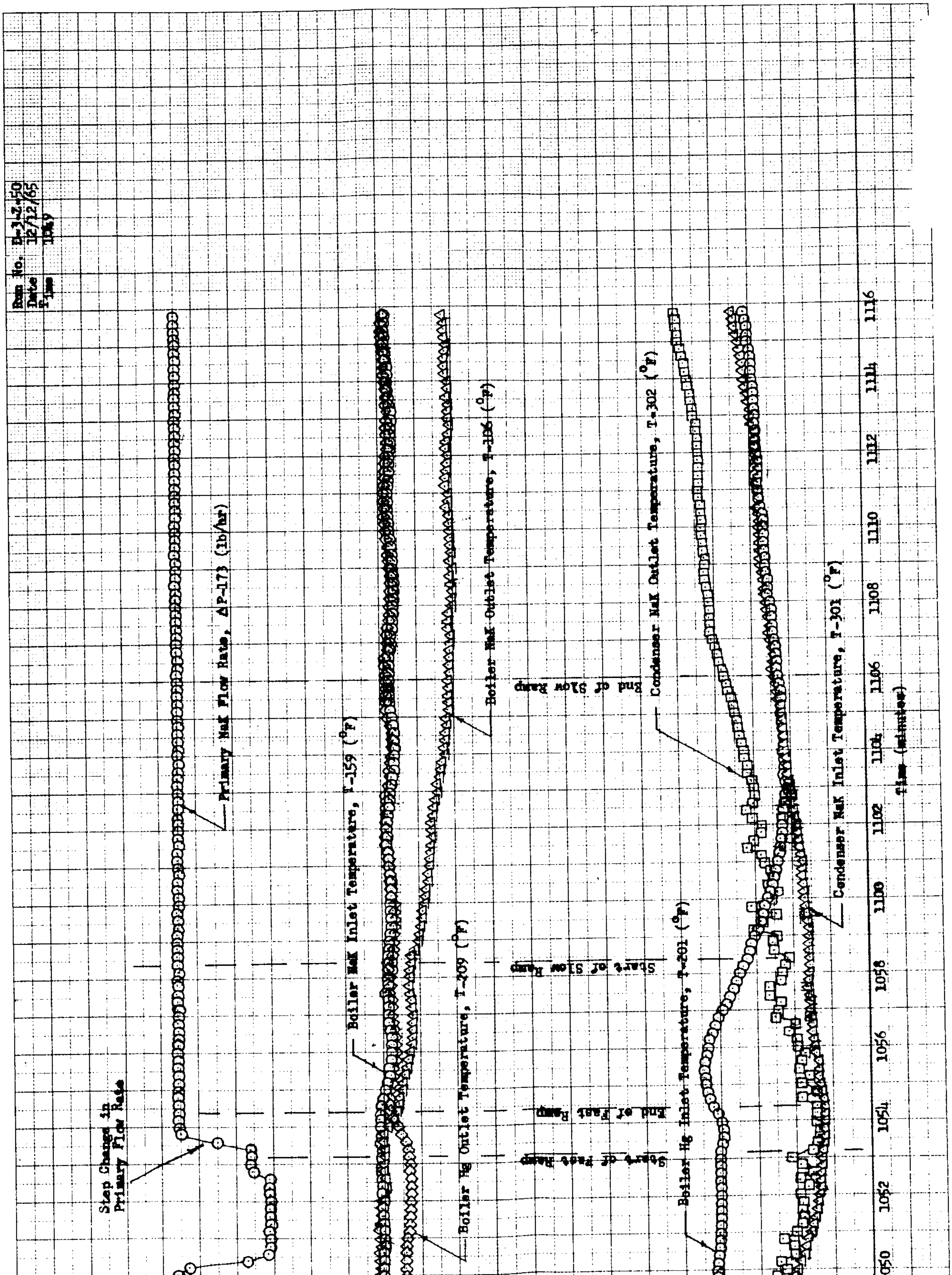
Figure VI-46



Boiler Transients Showing Mercury Side Response to Simulated Injection Startup No. 2

B166-NF-1150

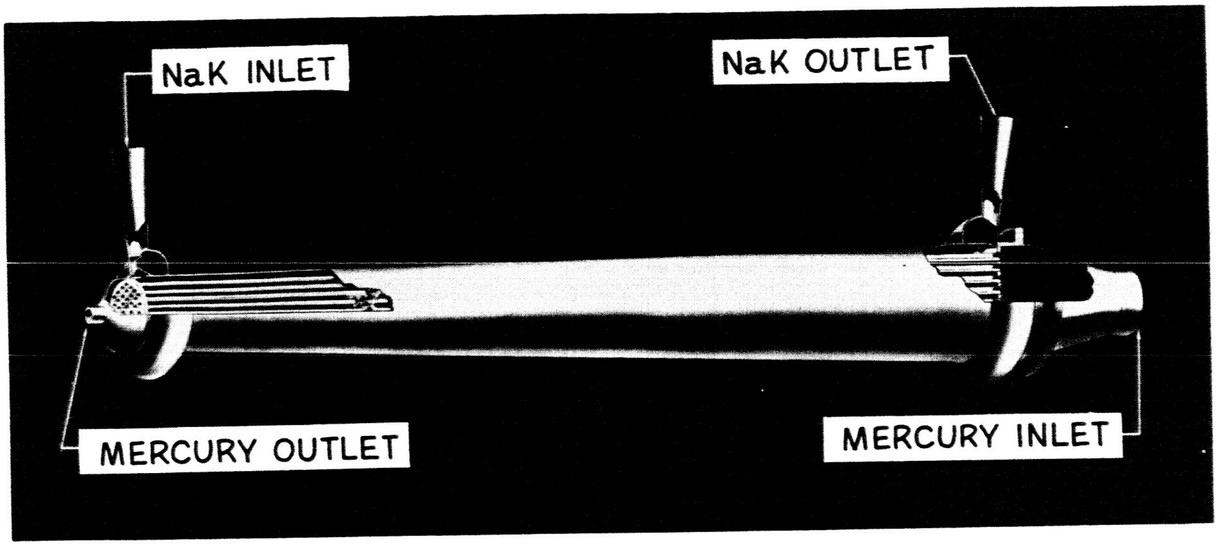
Figure VI-47

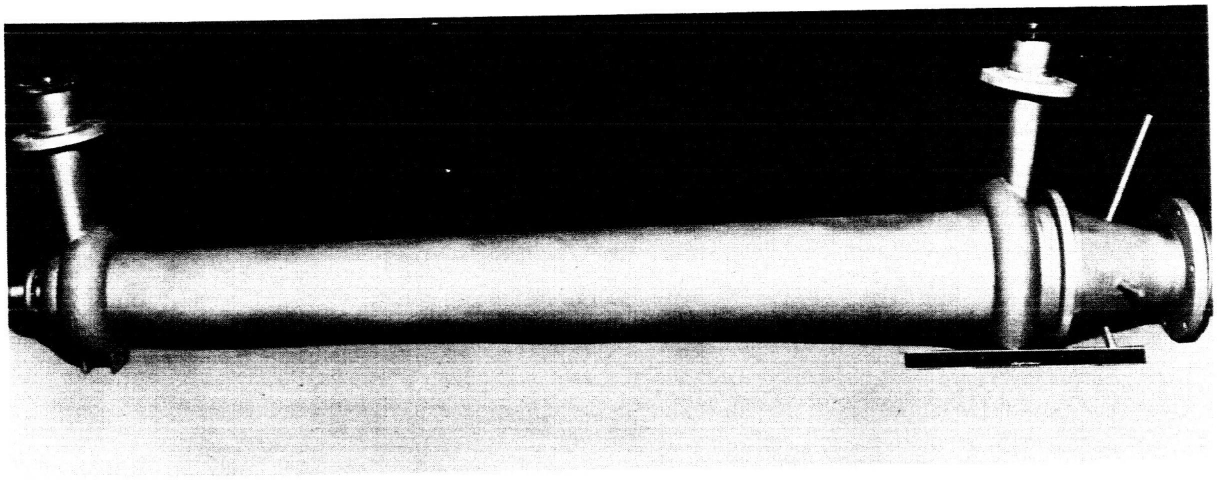


Boiler Transients Showing NaK Response to Simulated Injection Startup No. 2

A166-NF-1151

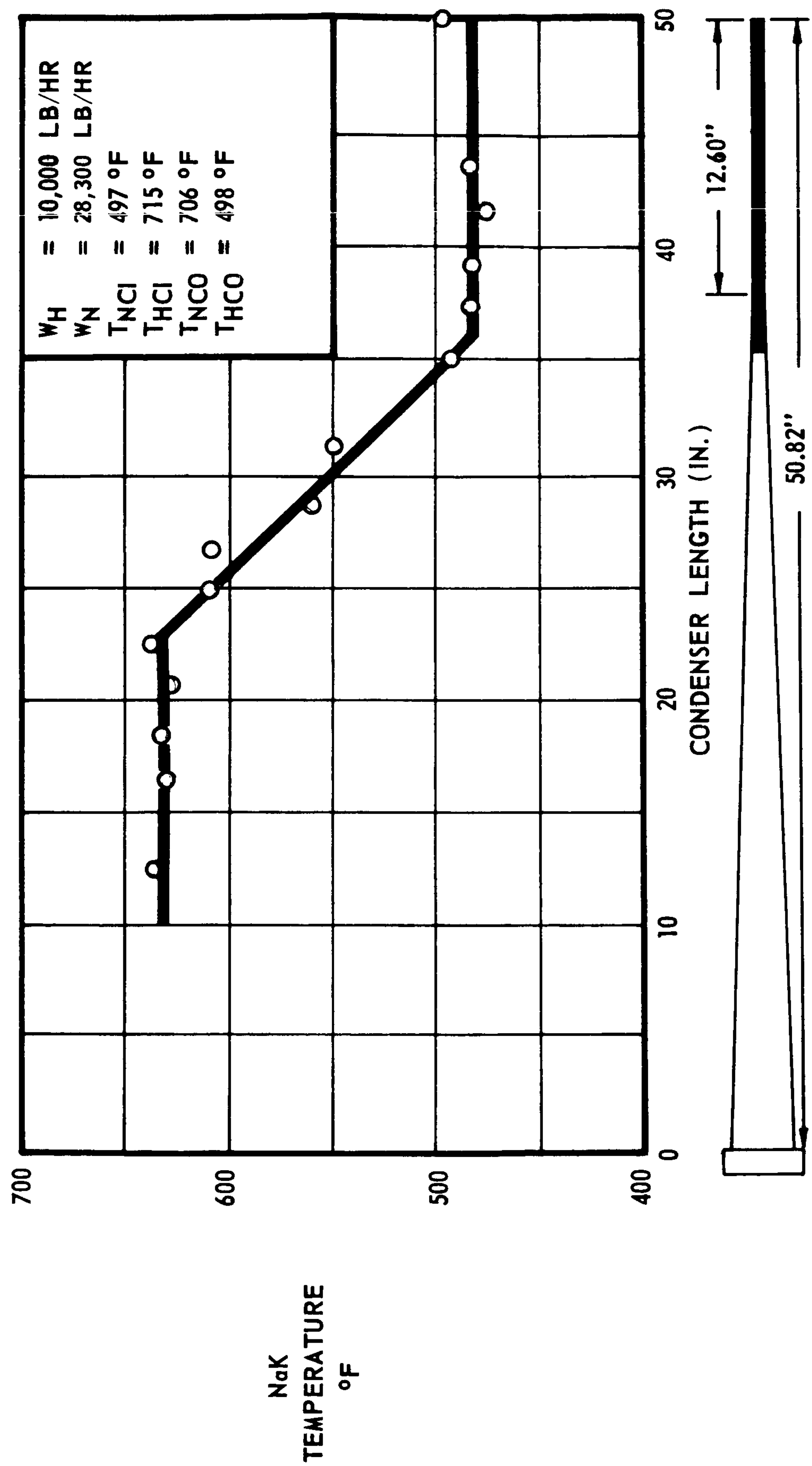
Figure VI-48





SNAP-8 Condenser and Cutaway Drawing Showing Cross-Counter Flow

Figure VI-49

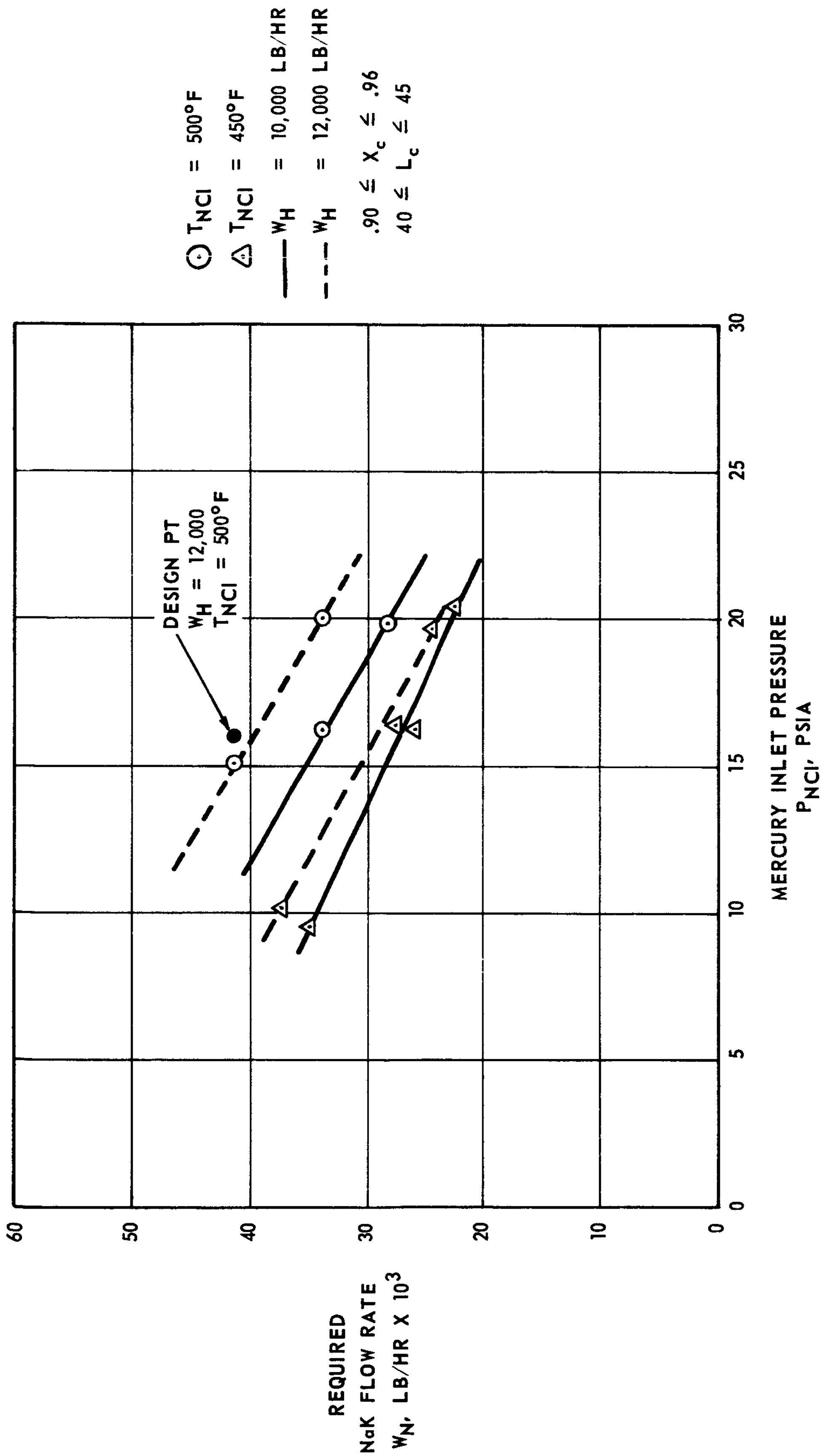


PCS-1 Phase IV Step 1 (RPL-2) Condensing Temperature Profile

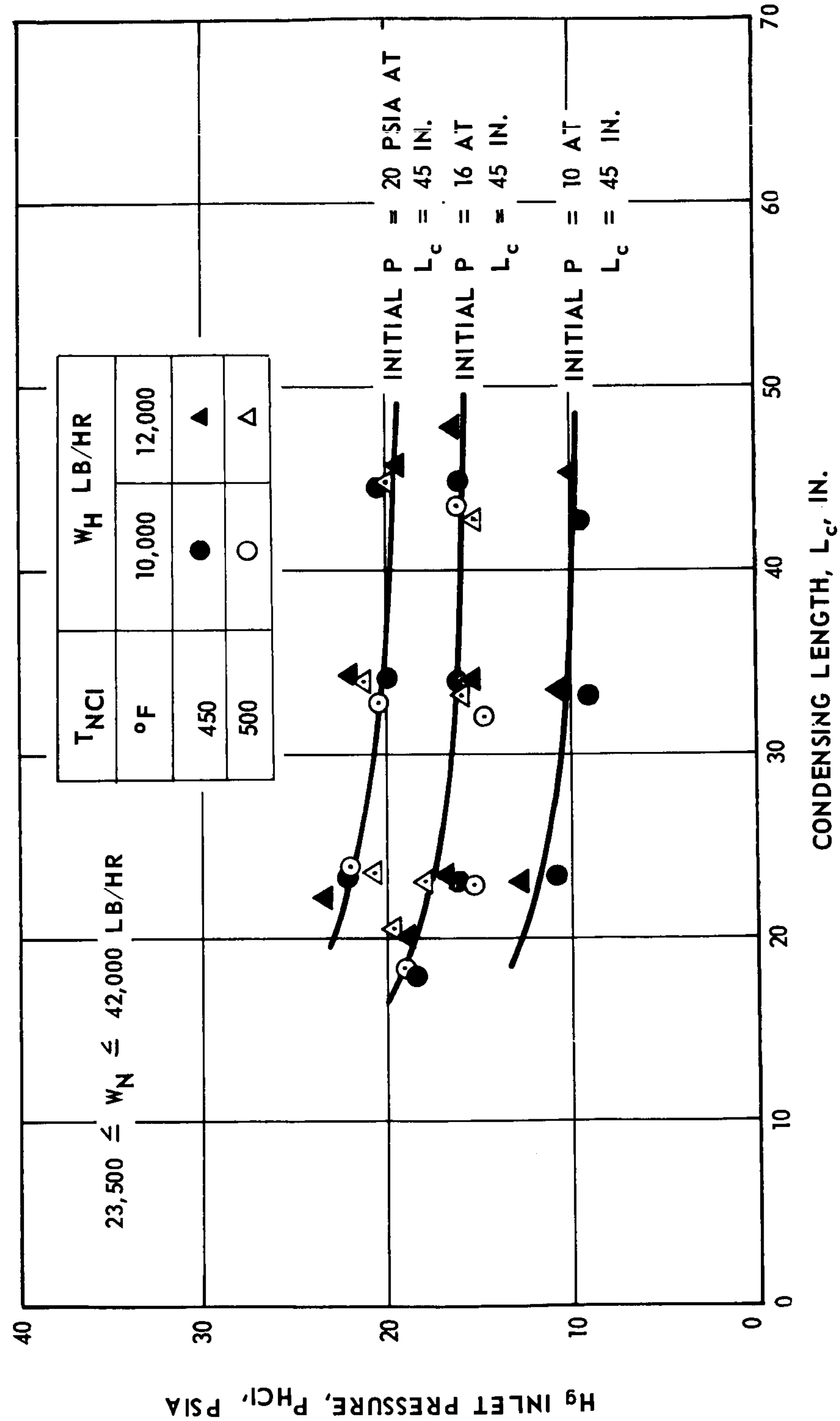
166-160

Figure VI-50

A166-NF-1176/A

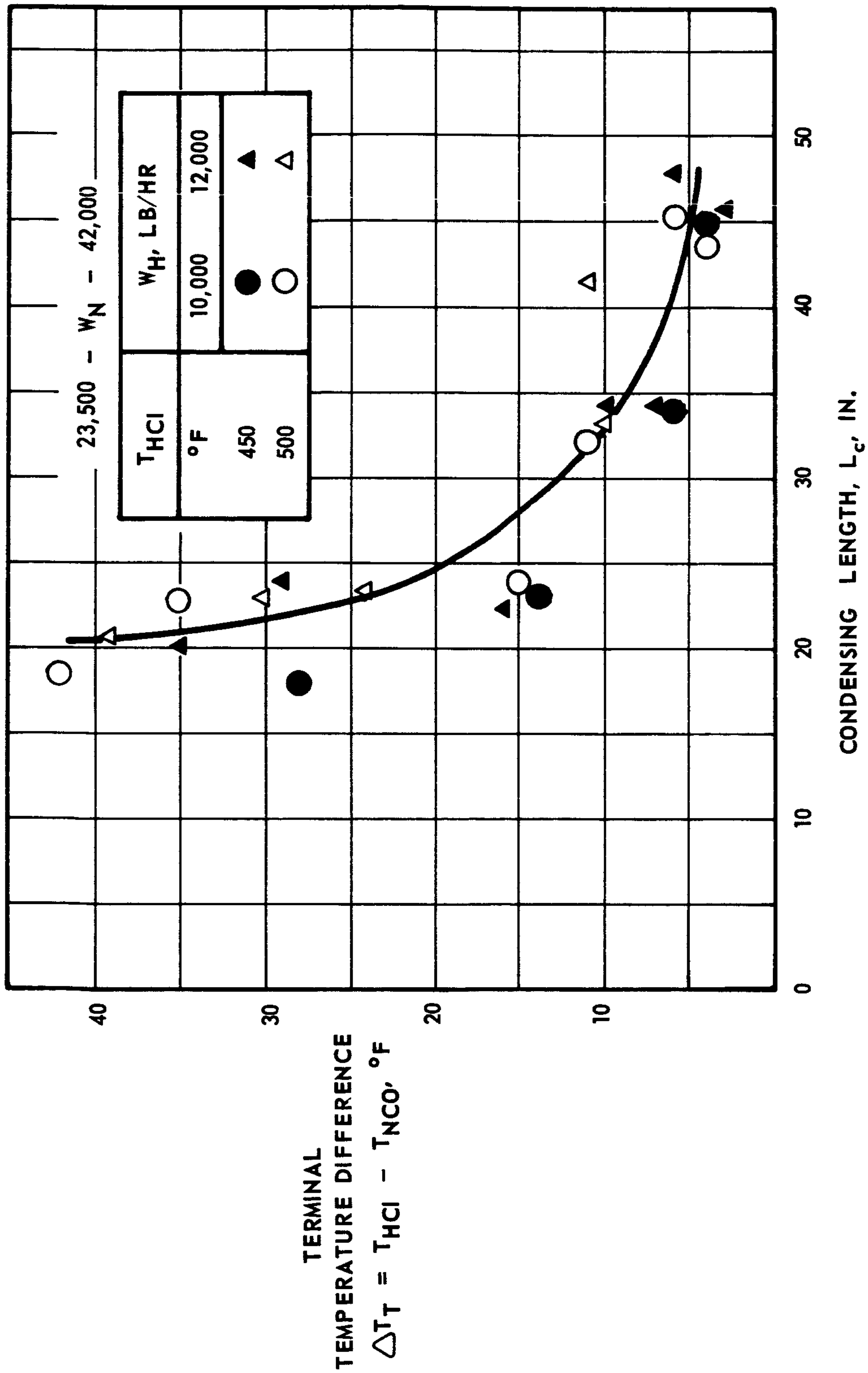


Required Heat Rejection Loop Flow Rate During
PCS-1 Phase IV Step 1 Condenser (P/N 092500-1, S/N A-2)
Tests - 9-10 December 1965, (Run D-3-Z-50)



PCS-1 Phase IV Step 1 Condenser (P/N 092500-1, S/N A-2) Tests (Run D-3-A-50) 9-10 December 1965. Condensing Pressure vs Length

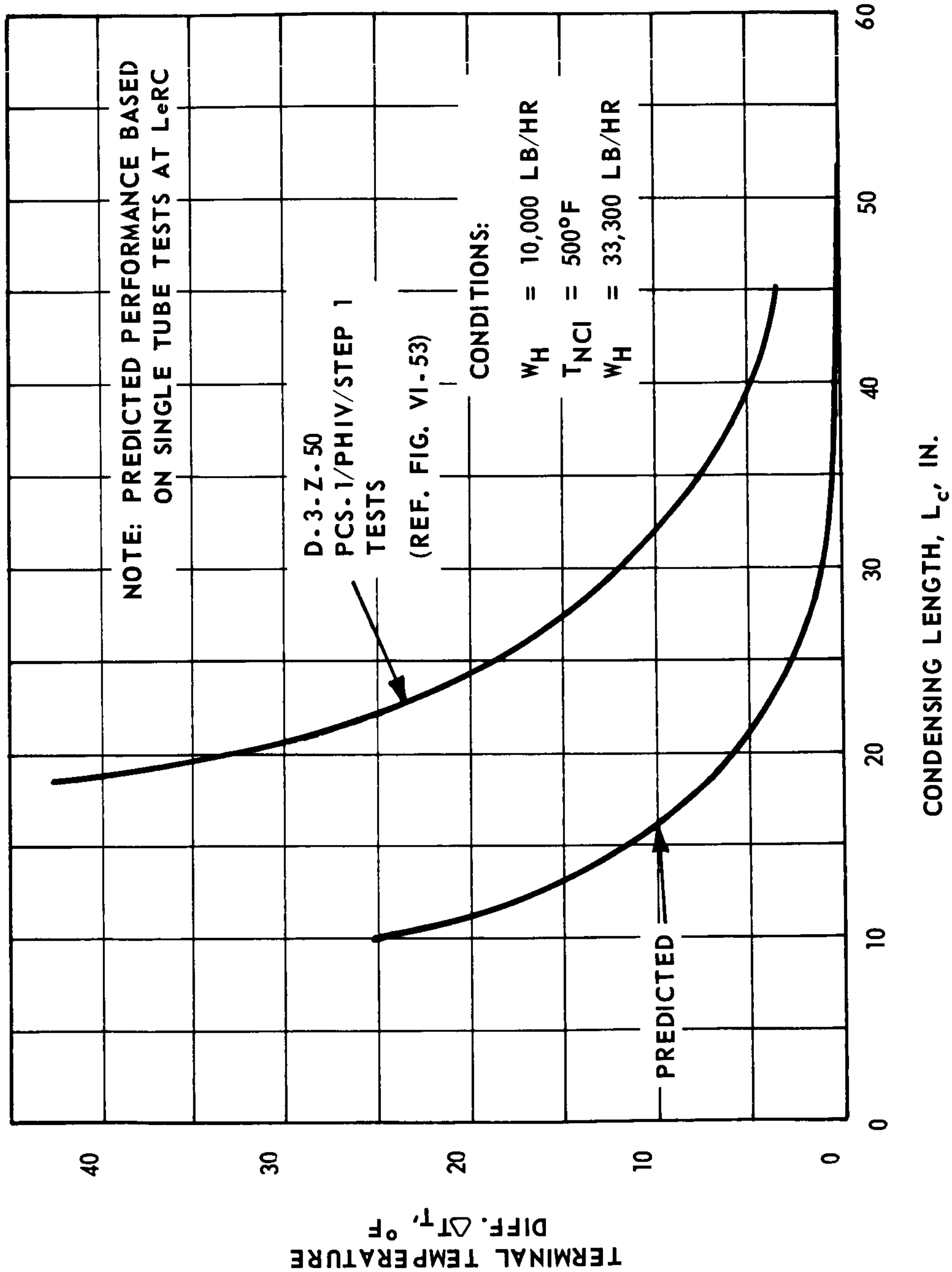
A166-NF-1178/A



A166-NF-1179/A

PCS-1 Phase IV Step 1 Condenser (P/N 092500-1,
S/N A-2) Tests (Run D-3-Z-50) 9-10 December 1965

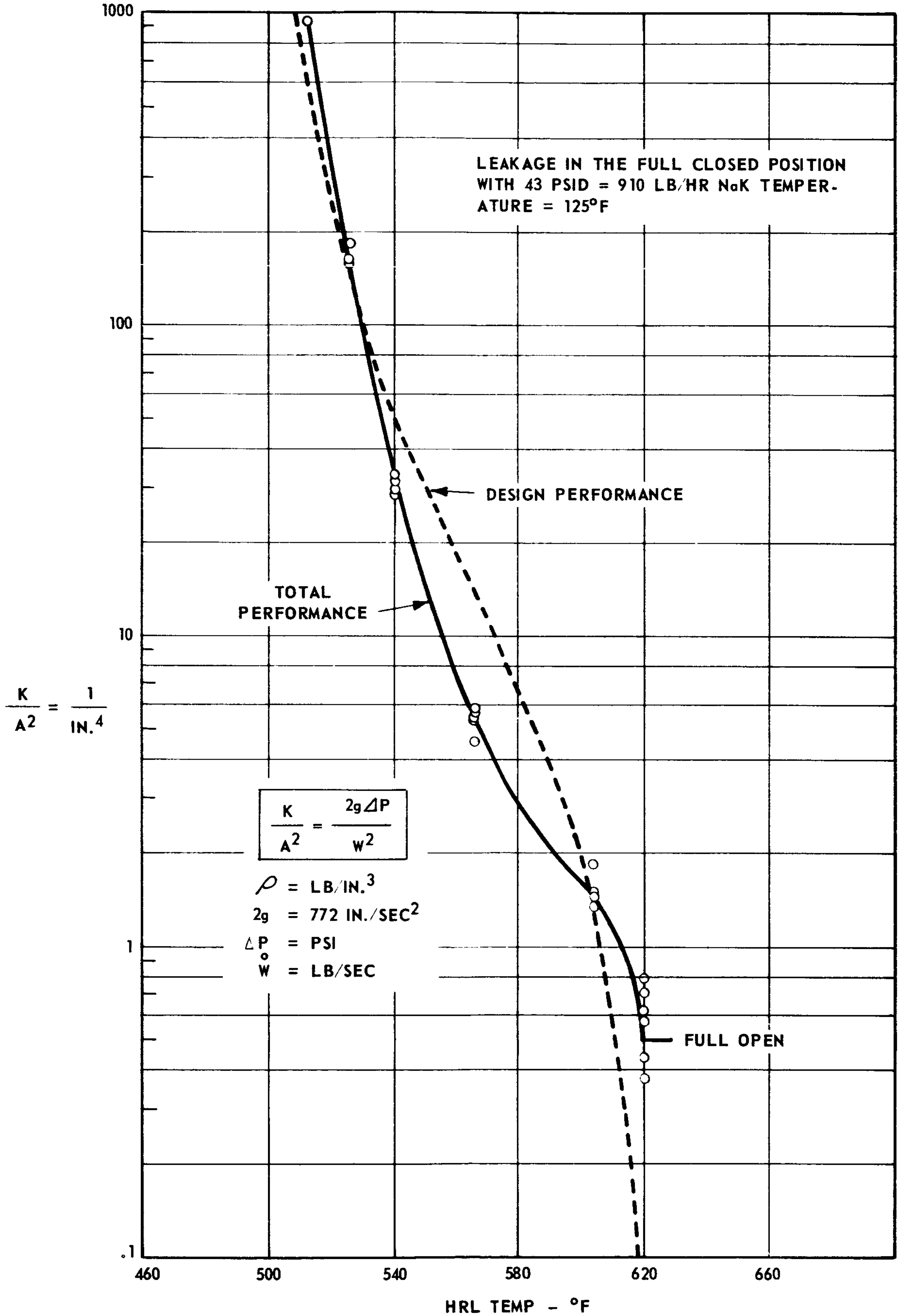
Figure VI-53



Terminal Temperature Difference Showing Comparison of Test and Predicted Performance

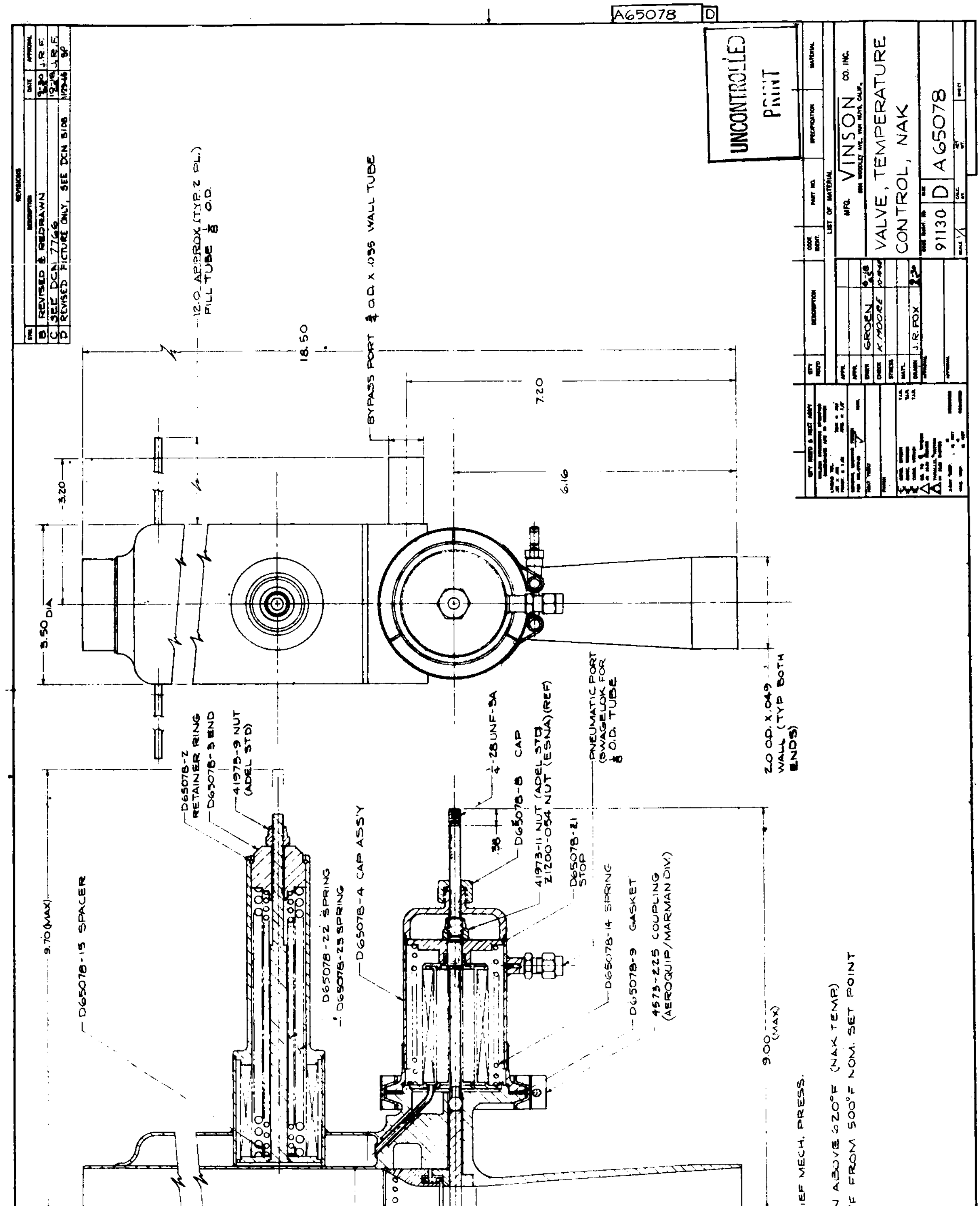
A166-NF-1180/A

Figure VI-54



Total Performance Curve for the Roylyn Temperature Control Valve (S/N 001)

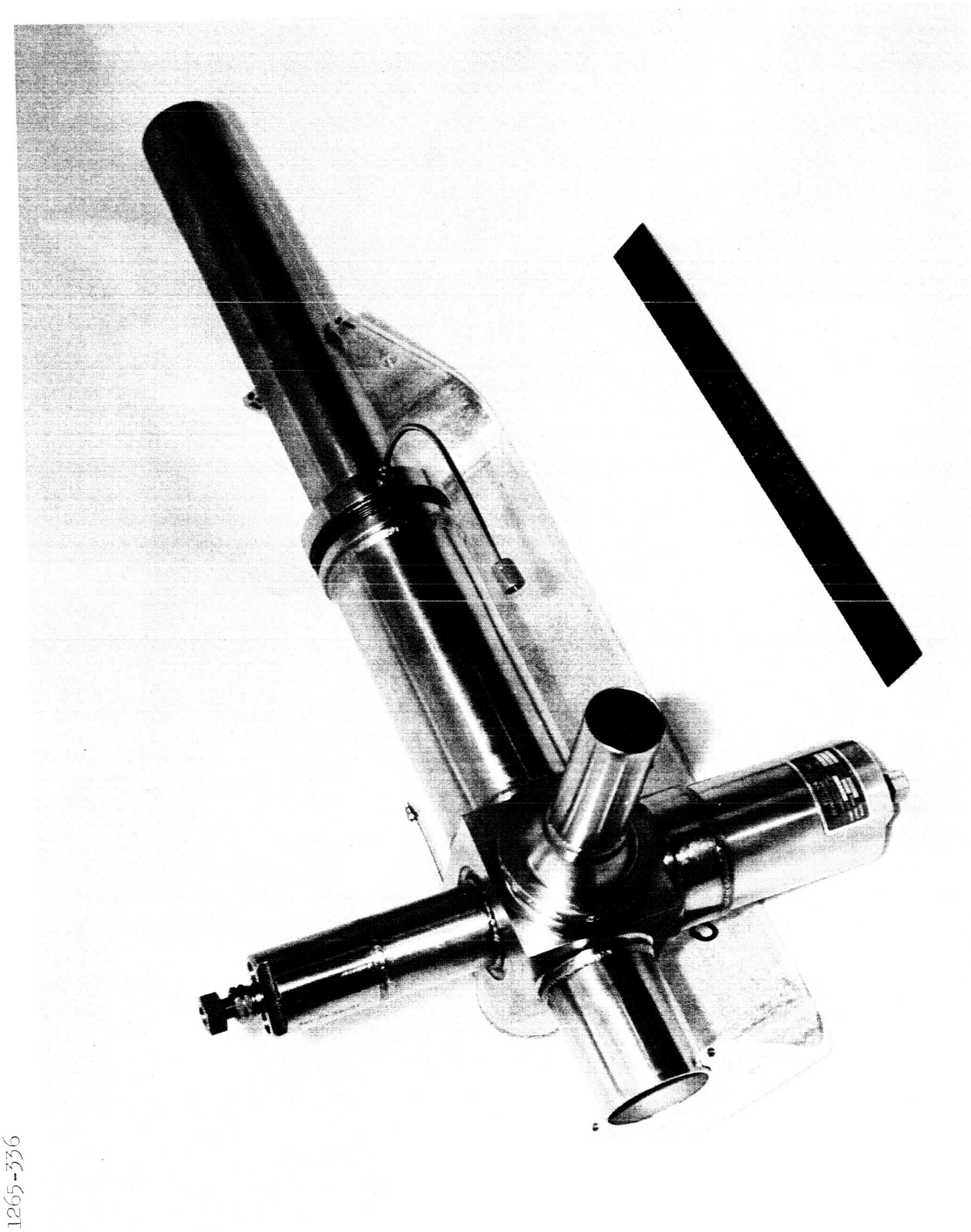
Figure VI-55



Temperature Control Valve (TCV)

Figure VI-56

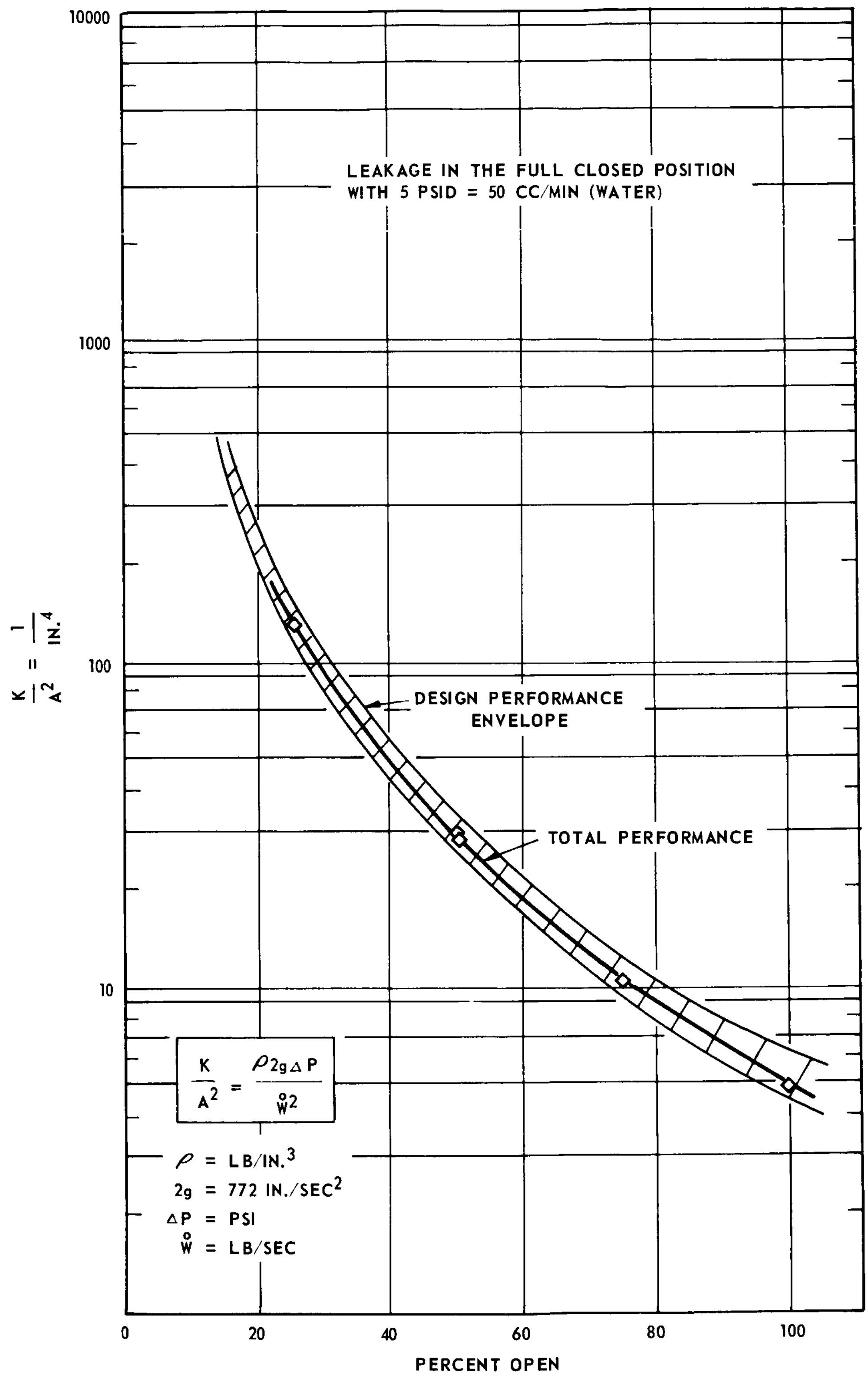
466-285



1265-336

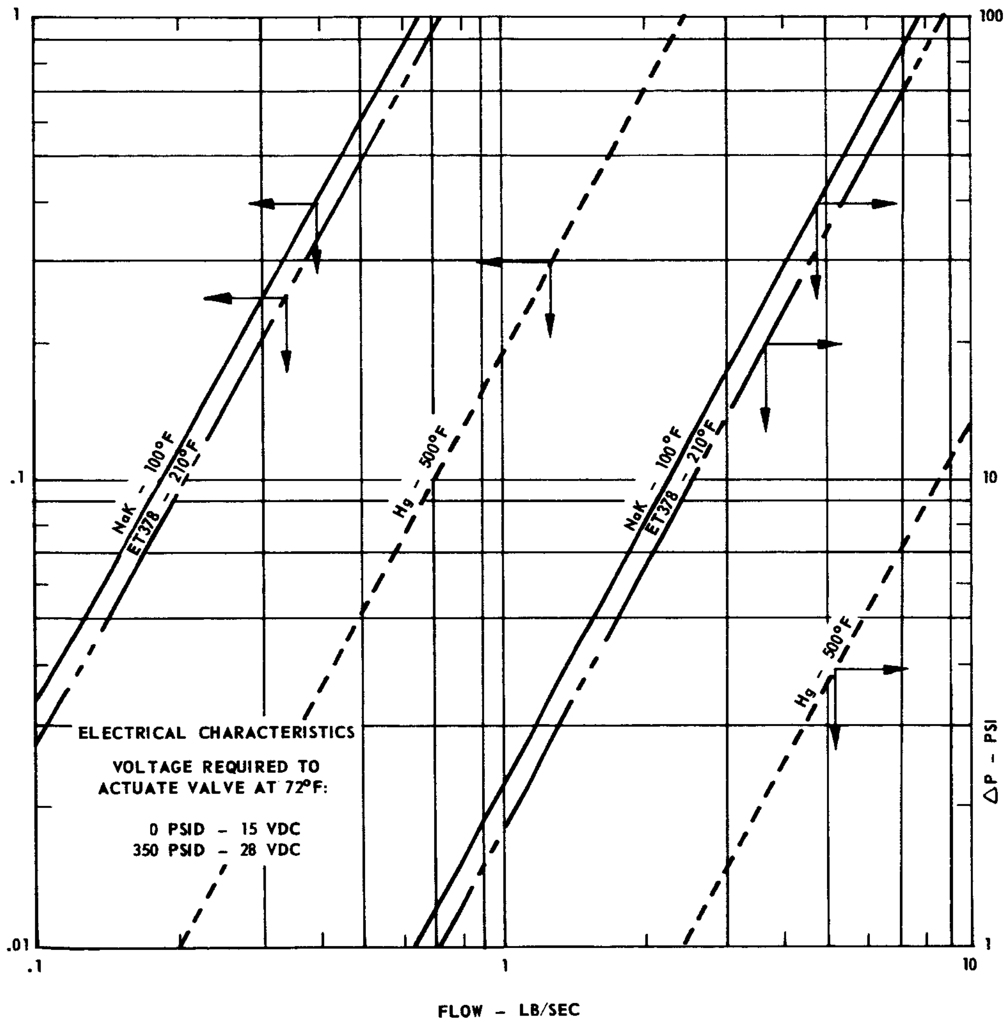
Condenser Bypass Valve (CBV)

Figure VI-57



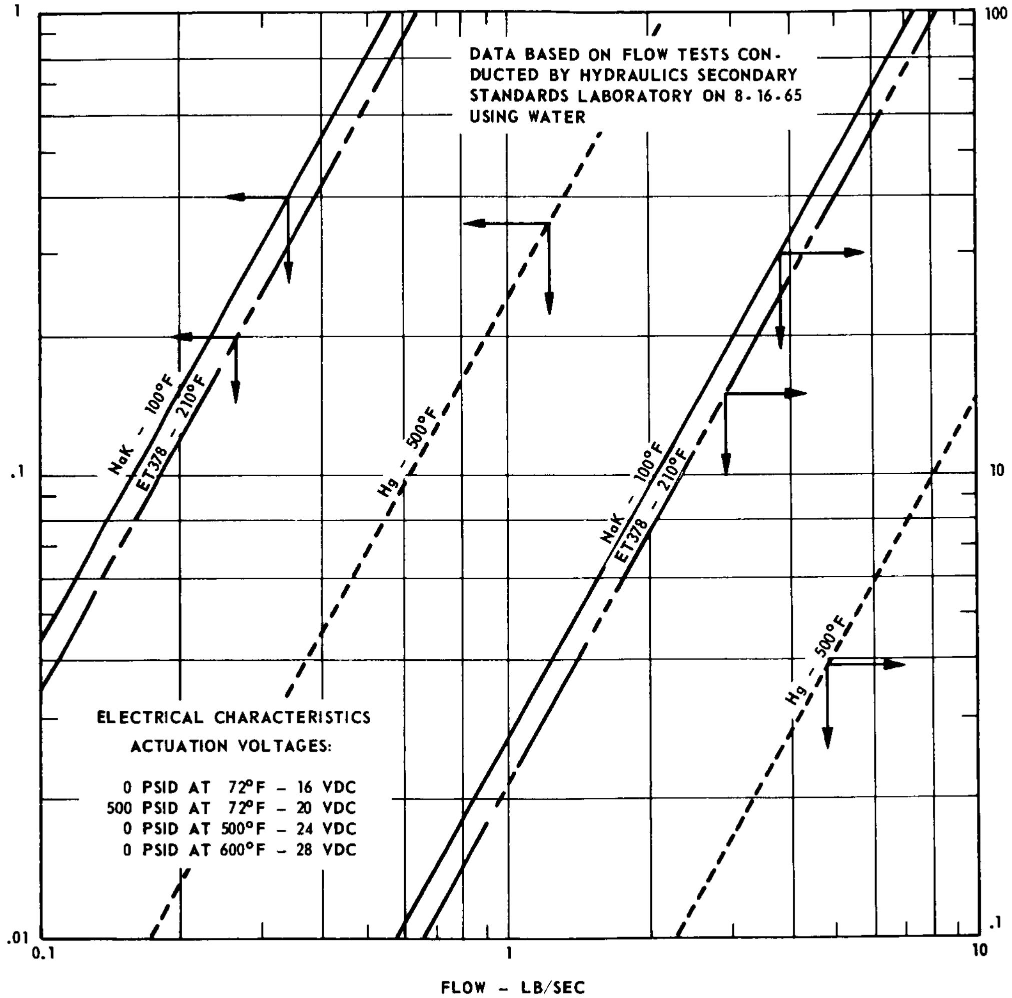
Total Performance of the Condenser Bypass Valve

Figure VI-58



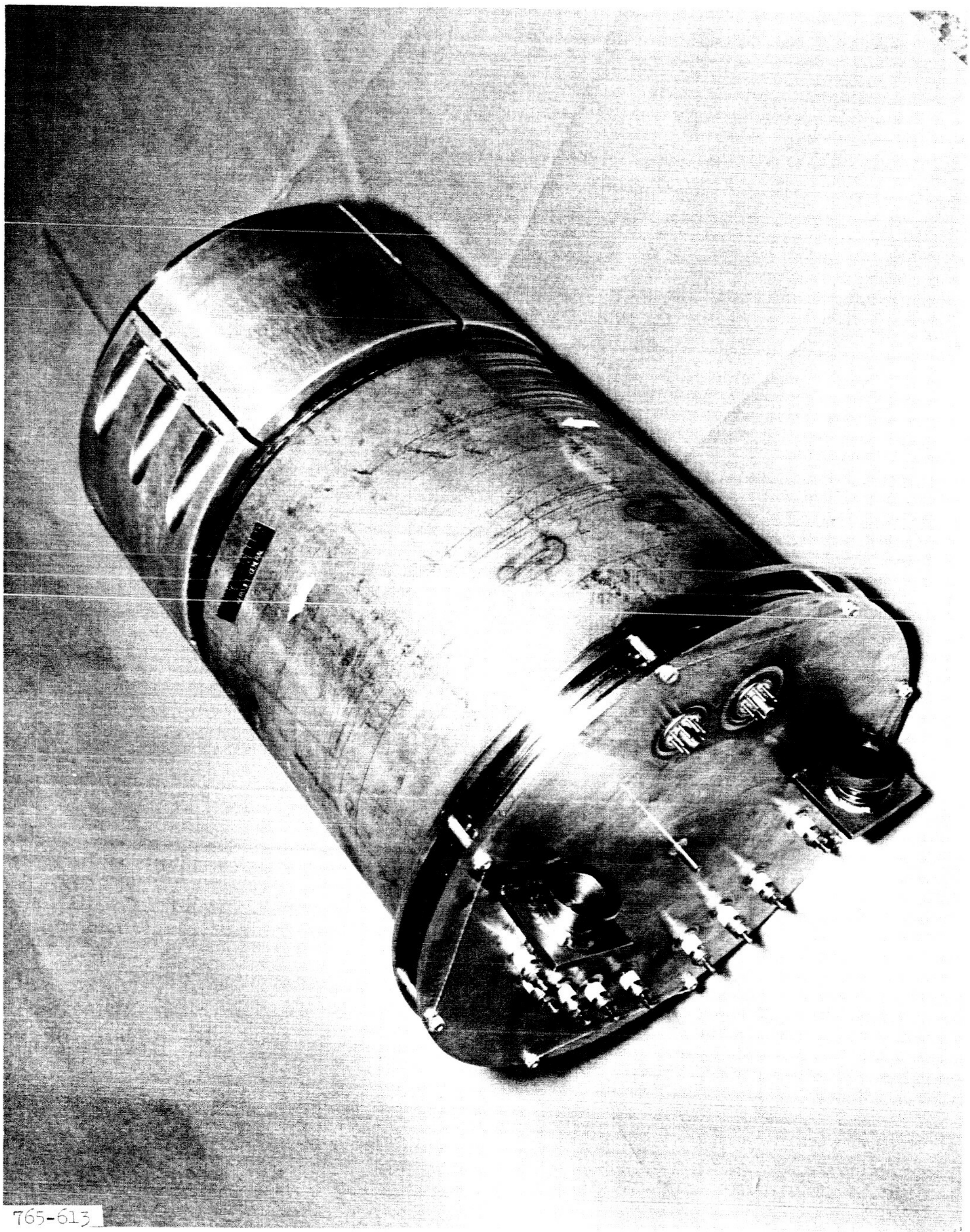
Flow Characteristics of Valcor (V-54600-06) Double
Solenoid Latch Valve, Serial No. 4

Figure VI-59



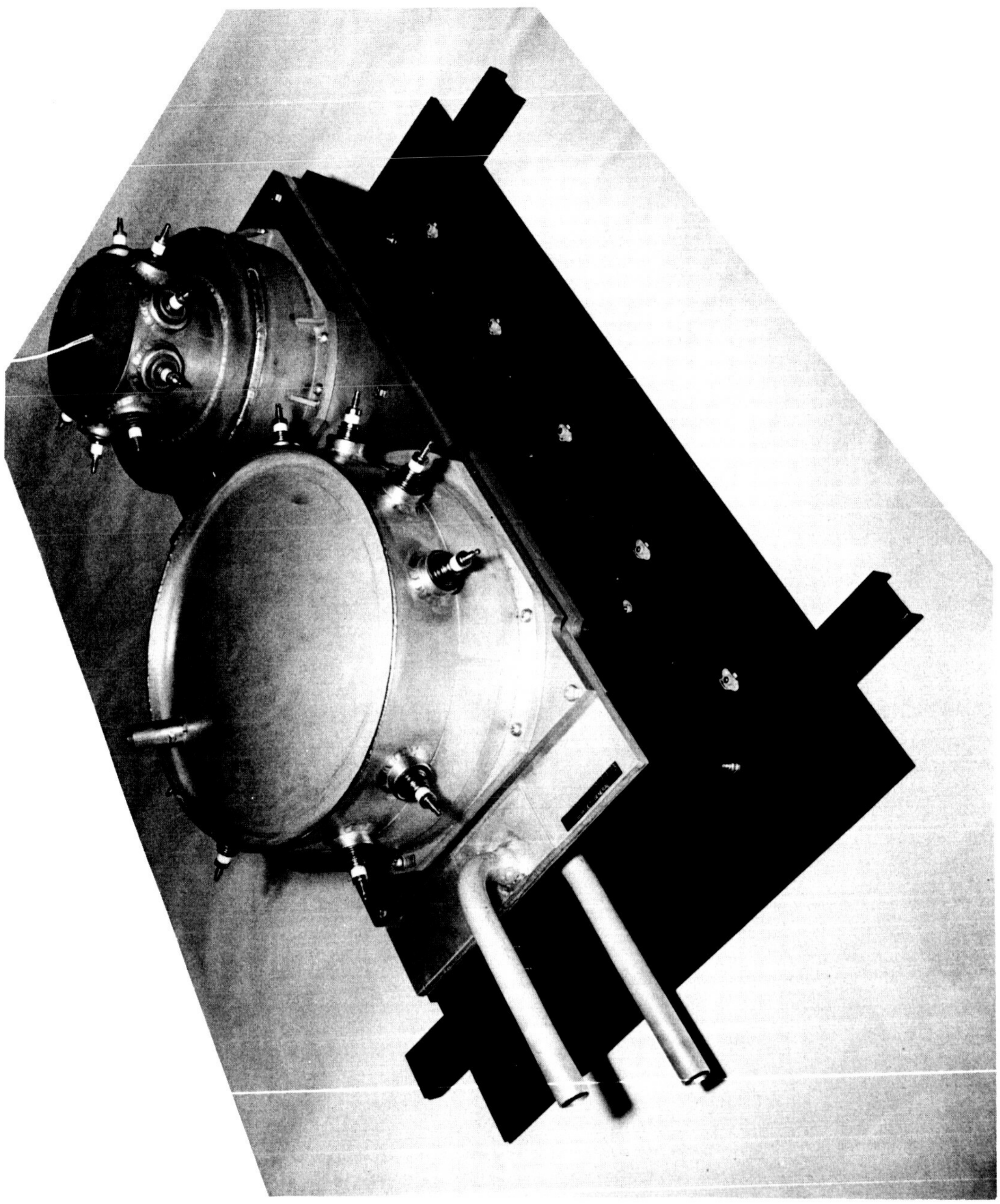
Flow Characteristics of Valcor (V-54600-06) Double Solenoid Latch Valve, Serial No. 4

Figure VI-60



Rotary Inverter

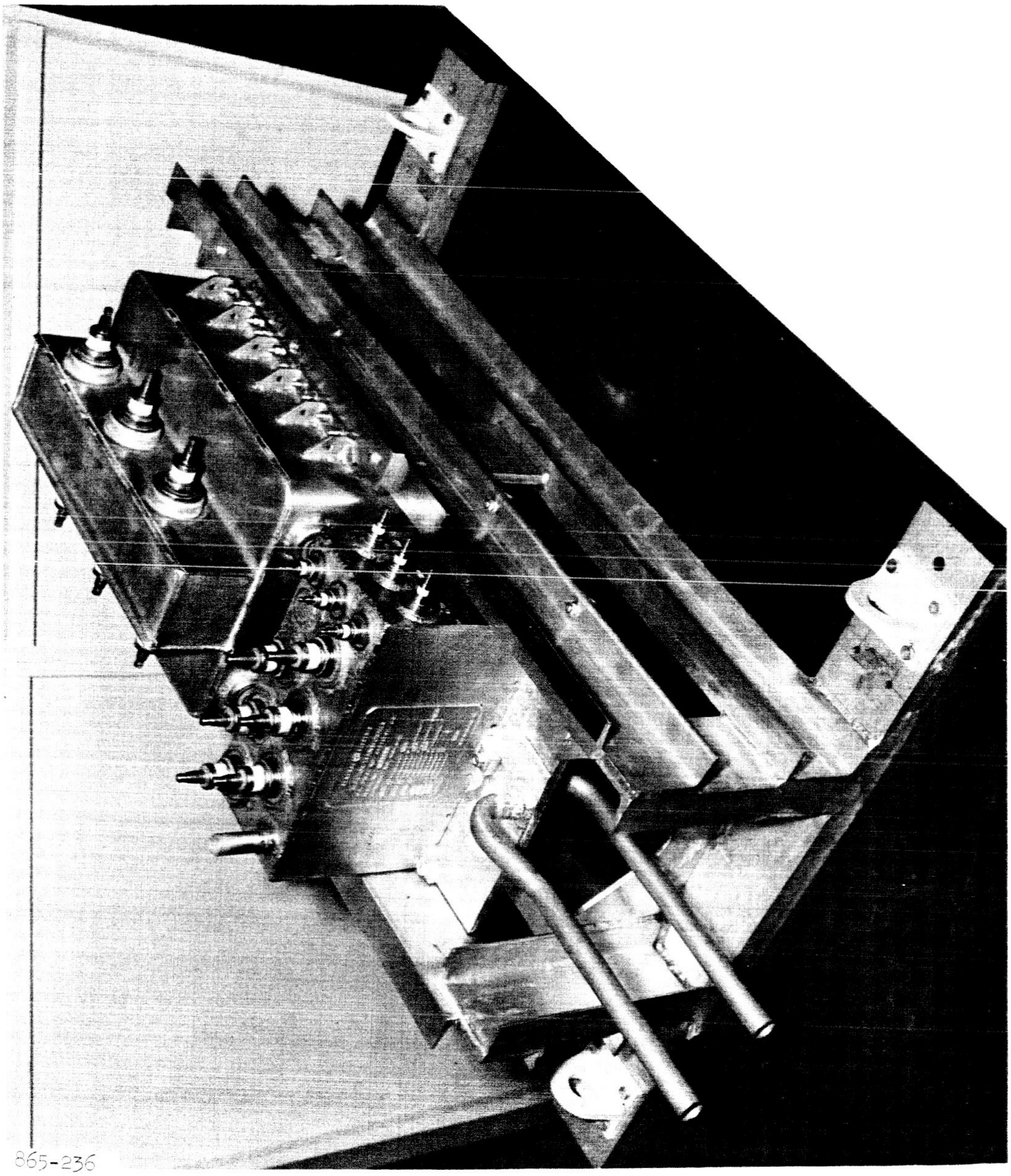
Figure VI-61



865-238

Low Temperature Control Assembly for PCS-1 Phase IV Step 3 Testing

Figure VI-62


865-236

Transformer Reactor Assembly for PCS-1 Phase IV Step 3 Testing

Figure VI-63

VII. TECHNICAL SUPPORT

A. SYSTEMS ANALYSIS

1. PCS-1/SL-1 Support

a. Mercury Flow-Control Valve Characteristics

The mercury flow-control valve to be used for the start-up development and demonstration testing period of PCS-1 Phase II operations was made by the Valcor Engineering Company according to Aerojet specifications. The specifications represented desired valve characteristics based on the projected operating conditions and mercury loop configuration for PCS-1 Phase II.

Valve calibration tests, conducted by an independent laboratory, showed values of pressure drop and mercury flow rate as functions of valve position, and showed valve opening time as a function of drive-motor voltage. The results of the flow and actuation tests were used to determine the operating characteristics of the valve when installed in the PCS-1 Phase II system. The valve characteristics were determined assuming that a tube-in-tube boiler would be used and that no condensation would occur between the boiler and turbine during startup. The actuation characteristics of the valve are shown in Figure VII-1 as curves of valve orifice position vs opening time for various drive-motor voltages. The flow characteristics of the valve, when incorporated in the mercury loop projected for PCS-1 Phase II, are shown in Figure VII-2 as curves of valve orifice position versus mercury flow rate for various pressure drops across the valve. The resultant actuation and flow characteristics of Figures VII-1 and VII-2, when used in conjunction with a flow/pressure-drop analysis of the remainder of the mercury loop, can be used to determine the desired mercury flow programs for startup tests.

b. Heat Rejection Loop Temperature Control Valve Characteristics

The operating characteristics of two temperature control valves, made by Roylyn, Inc., according to Aerojet Specifications, were determined using flow test data supplied by the manufacturer and actuation test data obtained at Aerojet. The actuation tests conducted at Aerojet showed the operating characteristics of the valve as a function of NaK temperature at the condenser.

The flow and actuation test data were used in an analysis of startup conditions in the heat rejection and auxiliary start loops of the reference system. The results of the analysis for the two valves (S/N 001 and S/N 002) are shown in Figures VII-3 and VII-4 as valve, heat rejection loop, and auxiliary start loop flow rates as functions of NaK temperature at the condenser outlet. Figures VII-3 and VII-4 also show the specified values for the same functions.

A comparison of the curves of calculated and specified characteristics for S/N 001 valve (Figure VII-3) indicates noticeable differences in the various flow rates as a function of condenser outlet NaK temperature. Therefore, the valve is not completely satisfactory for use in startup development tests. A comparison of the curves of calculated and specified characteristics for S/N 002 valve (Figure VII-4) indicates that this valve would be unacceptable for use in startup development tests.

Since the temperature control valves that have been received to date do not meet the specified requirements, a new valve design is being considered. However, if a valve of the new design is not received in time for use during the startup development test period, the Roylyn valve, S/N 001, could be used for a limited amount of testing.

c. Recommendations for -X Start Programer Changes

Recommendations for changes in the -X start programer sequence were made as a result of component design changes and operational experience gained during PCS-1 Phase I testing. The changes are to be applied to the -X start programer which will be used for startup development testing. The recommended changes are concerned with the proper sequencing of the L/C inlet and outlet valves at the bearings of both the TAA and mercury PMA. The inlet and outlet valves of the TAA and mercury PMA should be opened simultaneously when a TAA speed of 8000 rpm is reached; this corresponds to an alternator frequency of approximately 270 cps. An interlock should be provided to assure that the inlet valve will not be opened unless the outlet valve has opened. This recommended procedure will assure that L/C fluid does not enter the bearing and seal cavities before the bearing slingers are operative.

2. Turbine and Vapor Line Condensation Effects

The study to determine the effects on startup conditions of condensation in the vapor line between the boiler and turbine and in the turbine continued. The initial efforts for this study were discussed in the previous semiannual report (Ref. 27) in which the mathematical model and appropriate assumptions were described for the condensation phenomena occurring in the vapor line. The mathematical model has been extended to include three phases of startup flow conditions - condensation, reevaporation and dry vapor - for both the vapor line and the turbine. To simplify the calculations, the general assumption was made that, during the condensation and reevaporation phases, the vapor leaving the turbine would be 100% saturated. A digital computer program was written for the mathematical model and checkout runs were made using hypothetical startup conditions based on results obtained from previous hybrid computer startup studies.

To obtain realistic startup conditions, the off-design performance characteristics of the boiler must be known at low mercury flow rate and pressure conditions. When these boiler characteristics are combined with the digital program for calculating the condensation and reevaporation processes occurring in the vapor line, corresponding inlet conditions to the turbine can be determined.

An attempt was made to obtain a boiler performance map using the PROBOPEAN computer code. The PROBOPEAN code was developed to determine configurations and off-design performance of tube-in-tube boilers. However, unsatisfactory results were obtained from this code at mercury flow rates below approximately 70% rated, and a suitable boiler performance map was not obtained.

The recent tests conducted with the tube-in-tube boiler in the PCS-1 Phase IV test facility are expected to yield a significant amount of boiler off-design performance data. A boiler performance map will be constructed from these data and incorporated with the computer program for determining condensation in the vapor line to the turbine.

3. Condenser Pressure Drop Correlation Investigation

An investigation was initiated to determine a suitable condenser pressure drop relationship that will be useful for steady-state analyses and for incorporation in hybrid computer simulations of the SNAP-8 system. Several methods of computing two-phase pressure drop will be evaluated and the results compared with MECA test data before a condenser pressure drop relationship is selected.

The Baroczy-Sanders method of determining two-phase pressure drop is presently being investigated and a digital computer program was written for calculating condenser pressure drop by this method. A checkout run will be made using condenser design conditions and, if satisfactory results are obtained, additional runs will be made at off-design conditions. The results of the off-design condition calculations will be compared with the MECA test results to determine the applicability of this method.

4. Analysis of System Based on Unmodified -1 Component Performance

An analysis of a SNAP-8 system, consisting of unmodified -1 components with performance as tested to date in conjunction with a reactor and space radiator, was performed to determine if an electrical output of 35 kw could be obtained. In addition, the analysis was performed to determine the required system flow rates, pressures, and temperatures for a system producing 35 kwe output and to ensure that any component limitations would not be exceeded. The results of the analysis showed that the proposed system could produce the desired electrical output without exceeding component limitations. Figure VII-5 presents the system diagram on which all significant flow, pressure, temperature, electrical power, and heat load values are shown.

A technical memorandum (Ref. 44) was published which describes the assumptions, analytical methods, results, and conclusions used in the analysis.

5. SCAN - Steady-State System Performance Computer Program

The analysis of the SNAP-8 system utilizing unmodified -1 components was used as the basis for developing a digital computer code to solve steady-state system performance problems. The analytical expressions, basic computation techniques, and component performance curves presented in Ref. 44 were, in general, incorporated in the computer code. The computer code was labeled SCAN, an acronym for SNAP-8 Cycle ANalysis.

As presently written the SCAN computer code consists of 54 functional equations that contain 69 variables. Therefore, 15 independent variables must be specified before a solution can be obtained. The resulting equations are solved by an iterative scheme using a modification of the Newton-Raphson method. The computer code was checked out and sample problems were run. The flexibility of the code will be investigated by solving a number of typical system problems such as variations in NaK temperature at the reactor outlet, variations in electrical power to the parasitic load resistor, sun-shade variations, and system operation at different net electrical power output levels. The SCAN code will be applied in the near future to study operating conditions of the PCS-1, Phase IV system. Later, the code will be used to update and maintain reference system performance data, and to characterize all future SNAP-8 systems, such as PCS-G.

6. Hybrid Computer Simulation for PCS-1 Phase IV

A simulation of the test loop arrangement of the PCS-1 Phase IV system will be programed on the hybrid computer. The computer simulation will be used to provide guidance for test planning and to aid in the interpretation of transient and steady-state test results.

The computer simulation of the reference system (Revision D) will provide the basis for the simulation of the PCS-1 Phase IV test loop arrangement. Extensive revisions will be required to simulate the gas-fired NaK heater in place of the reactor as the heat source and to simulate the air-blast heat exchanger in place of the space radiator as the heat rejection medium. All other system component simulations will be modified to reflect the latest -1 component performance values.

All equations for the primary loop have been written and appropriate computer diagrams are being prepared. Equations for the mercury and heat rejection loops are being revised or rewritten.

7. SEDAN Code Modifications

The SEDAN code, which has been used for analyzing SNAP-8 system and component test data obtained from RPL-2, was modified to account for the changes in boiler instrumentation necessitated by the changes in the tube-in-tube boiler plug configuration. The modified code has been checked out and will be used for analyzing data from the boiler and condenser performance mapping test runs.

Further modifications are being made to the SEDAN code in preparation for PCS-1 Phase IV Step 2 testing. Modifications include provisions for determining performance of the TAA and NaK-PMAs that will be tested in the PCS-1 Phase IV system.

B. MATERIALS*

Materials work during the second half of the 1965 calendar year provided data to guide the selection of materials for SNAP-8 system components. Metallurgical assistance was also provided in the design, development, fabrication, and testing of that system.

1. Test Operations Support

A study was conducted to evaluate the amount of wall thickness depletion that occurred during operation of the two gas-fired NaK heaters used in the RPL-2 system (2300 hr for heater No. 1 and 3220 hr for heater No. 2), and to estimate the probable remaining heater life. The wall thicknesses of the 316 SS NaK containment pipe coils of the heaters were measured by the ultrasonic pulse-echo technique. Calculations based on estimated maximum oxidation-corrosion

*Under the terms of the SNAP-8 contract a Semiannual Materials Report (Ref. 45) is prepared covering the same time period covered in this Semiannual Progress Report. The Semiannual Materials Report is summarized in this section. For specific details, the reader is referred to the complete report.

rates for the previous operating history, indicate that the heaters will operate for a minimum of an additional 9100 hr before the wall thickness is reduced to the minimum allowed by the ASME Boiler Code.

Metallographic examination of a 3/8-in.-dia, 0.049-in. wall, 316 SS instrumentation tube removed from the Hg exit manifold of the -1 boiler, indicated that surface corrosion had occurred toward the hot end of the area of presumed Hg refluxing action. Assuming a uniform corrosion rate, a wall depletion rate of 7.7 mils/1000 hr occurred. Presuming that this rate of wall depletion continued, it would have required slightly less than 5000 hr of total boiler operating time to reduce the tube wall thickness to the minimum allowable specified by the ASME Boiler Code for the existing vapor conditions. Instrumentation taps of 316 SS exposed to the above conditions would therefore not be satisfactory for a 10,000-hr system. It was recommended that 9Cr-1Mo or a 400 series SS be substituted for the 316 SS.

Contamination of the Hg-exposed surface in the tube-in-tube boiler and of the Hg inventory in the SL-1 system was found. The contaminants were mix-4P3E (the L/C loop fluid) and an aliphatic hydrocarbon (probably Duo-seal vacuum pump oil) as fluids and as thermally decomposed residues. The Hg loop and components were cleaned, however, later in the test sequence; recontamination was detected, apparently caused by an undetected pressure transducer failure that introduced silicone oil into the Hg loop.

The outer glass wrapping on the pipe insulation discolored during 1150 hr of NaK primary loop operation in SL-1. The discoloration is presumed to result from slow elevated-temperature decomposition, at approximately 300°F, of the butadiene adhesive used in the outer layer of the piping thermal insulation system. It was further ascertained that the adhesive spontaneously and rapidly decomposes without a visible flame in the presence of quiescent air at some temperature above 502°F but not exceeding 1065°F. The material spontaneously ignites and burns in quiescent air at some temperature above 1065°F, but not exceeding 1200°F. The adhesive in the glass wrap of the loop pipe insulation system will add fuel to any fire in the test cell that raises the temperature of the material to the point of spontaneous ignition. Consequently, it was recommended that a review be made of the current usage of this adhesive in the test area.

A Rb injection system was installed and successfully operated during boiler tests conducted in the SL-1 test facility. The Rb addition sufficiently improved boiler performance to allow completion of boiler characterization tests. Depletion of the Rb content in the Hg occurred gradually, repeating the experience of previous loop tests on the SNAP-8 Program.

During PCS-1 Phase IV Step 1 testing, Hg loop samples were obtained and analyzed before startup and during various loop shutdown periods. No contamination of the PCS loop during Step 1 operation was apparent. The Hg emergency dump system, however, contained a small amount of aliphatic hydrocarbon. A recommendation was made to clean this system prior to Step 2 testing to avoid possible contamination of the PCS from this source. The Hg from the main and emergency dump tank was slightly alkaline. The source of this contamination is unknown, but the quantity detected should have had no effect on system operation.

A test program was completed which indicated that Hg decontamination of components could be performed safely using a solvent-solute rather than a dewetting reaction. A 70% nitric acid solution containing 1 or 2% sodium nitrite (rust inhibitor) will adequately decontaminate components fabricated of 9Cr-1Mo, 316 SS, and low-carbon steels. No detrimental attack of the metals occurred as a result of immersion in the solution for up to 45 min.

An industrial survey indicated that the use of castings for Nak containment in the primary loop of the SNAP-8 system was not recommended for 10,000-hr service. Shorter time periods would be possible if periodic non-destructive evaluation of the component were performed to detect incipient leaks. Castings may be used in the other, lower temperature, NaK loops when the castings are thoroughly inspected prior to installation to ensure freedom from defects.

2. Fabrication Support

Full-scale tube assembly samples representing the coiled tube-in-tube boiler were fabricated and evaluated to establish coiling limitations and design criteria. A 20.5-in. mean diameter coil sample contained no unacceptable metallurgical defects in either the 321 SS outer NaK containment pipe or the seven internal 9Cr-1Mo steel Hg containment tubes. It is concluded that fabrication of a SNAP-8 tube-in-tube boiler containing a mean coil diameter equal to, or greater than, 20.5 in. should not result in fabrication-induced discontinuities detrimental to 10,000-hr boiler operation life.

A procedure utilizing a brazing alloy was established for rigidizing the interstage pressure transducers on the turbine assembly and to protect against vibration-induced loosening during operation. Simulated joints produced with Easy Flo 3, a noneutectic silver brazing alloy applied by torch, resulted in satisfactory joints. Protection against Hg corrosion of the normally nonresistant silver alloy should be afforded by the primary seal of the Dryseal pipe thread used to make the housing and the transducer fitting.

3. Stellite 6B Evaluation

The difference in the mechanical properties of Stellite 6B in the face centered cubic (FCC) crystallographic structure and the hexagonal close packed (HCP) structure was studied. Stellite 6B in the HCP condition tends to be considerably more brittle and less impact-resistant than material in the FCC condition. No decrease in tensile proportional limit or tensile yield strength was apparent, although a lower ultimate strength appears evident. The latter indicates a tendency for the material to fail in a brittle fashion rather than to relieve high local stresses, as at the base of a notch, by plastic deformation. The tensile properties of Stellite 6B at 1200°F do not degrade with continued exposure (up to 700 hr) at 1200°F. The static modulus of elasticity of material in the FCC or HCP condition is not significantly different. With care in design, handling, and operation, Stellite 6B in the HCP condition should remain a satisfactory alloy for use in mercury-driven turbines.

Crystallographic transformation of the material was found to be accompanied by a volumetric contraction. The statistical results indicate there is a 99% probability that 99% of the measured contractions attributable to the crystallographic transformation of Stellite 6B from FCC to HCP structure will fall between 0% and 0.223%. Therefore, the linear dimension of Stellite 6B machined parts in the FCC condition will reduce when transformed to the HCP condition during turbine operation. The consequence may be a marked increase in the axial clearance of components produced during TA assembly, or a decrease of this clearance which may result in overstressing of parts.

The transformation phenomenon was studied as it relates to treatment of the material during fabrication and exposure of the fabricated component during turbine operation. Transformation of Stellite 6B components from the FCC to the HCP condition can be expected over the operating period of the turbine, if the standard solution anneal and stress relief treatment is used (2250°F, air cool followed by 1650°F, air cool). The transformation apparently is caused by depletion of the matrix of carbon in the form of precipitation carbides. The carbon is a strong FCC stabilizer, and its removal changes the chemistry of the matrix such that the FCC structure becomes unstable and transforms to HCP with time at temperatures above 1100°F. The rate and ultimate degree of transformation remains unclear.

Complete transformation during fabrication can be effected most of the time by a thermal treatment of solution annealed material at 1650°F for 4 hr, followed by 1250°F treatment for 48 hr. Some material lots are more sluggish in going through metallurgical changes than others so that X-ray diffraction analysis is required to ensure completion of the reaction. By pretransforming turbine component material, potentially detrimental transformation during operation (because of volumetric contraction) can be avoided. Based on test results produced thus far (the tests are still in process), the FCC structure of Stellite 6B apparently can be stabilized against transformation to HCP by quenching from the solution annealing temperature rapidly enough to prevent carbide precipitation either during the heat treat procedure or during subsequent turbine operation. Salt-quenched specimens exposed at 1065°F showed some slight transformation within the first 400 hr of exposure but beyond that point, up to 1083 hr accumulated thus far, no further change in either the X-ray diffraction pattern or hardness of the material has been detected. The microstructure remains essentially FCC.

4. Alternative Turbine Materials Evaluation

Various alloys, considered as substitutes for Stellite 6B as the SNAP-8 reference turbine material should the need arise, were exposed at elevated temperature to allow a preliminary evaluation of their metallurgical stability. At 1065°F the alloys* S-816, PH 15-7, Lapelloy, and 410 appear acceptably stable. At 1200°F all except S-816 appear to suffer a reaction which would, as a minimum, reduce their mechanical properties. A more complete evaluation of the exposure effects will be required to fully evaluate the appropriateness of any of these materials for the higher-operating-temperature turbine components.

5. Evaluation of -1 Boiler

After completion of a test series in RPL-2, the tube-in-shell -1 boiler was removed for material evaluation. The NaK side operated for 2350 hr and the Hg side for 1415 hr.

Dendritic-type NaK mass-transfer deposits, primarily iron with a significant amount of nickel and a lesser amount of molybdenum, were concentrated at the low-temperature NaK outlet end (1100°F). Some minor deposit was found at the inlet end (1300°F). The mass transfer is presumed to have been caused by a generally prevalent uncontrolled (probably high) oxygen content of the NaK throughout boiler operating life.

Microscopic examination of the NaK-exposed surface of the Hg containment tube revealed grain growth and concomitant decarburization (maximum approximately 0.030 in. deep), mass-transfer deposits (maximum approximately 0.002 in.), and tube cracking. The latter occurred at a 5-1/2 in. radius Hg tube bend at the Hg outlet manifold.

Macroscopic and microscopic examination of the Hg side of the tube revealed pitting (maximum depth, 0.0055 in.), mass transfer (maximum depth, 0.004 in.), unexplained surface decarburization toward the Hg outlet end, and surface cracking at various locations. The internal mild steel ribbon turbulator

---

*Note:

S-816:	Cobalt-base alloy containing 20% each of Cr and Ni, and 4% each of Fe, Mo, W and Cb.
PH 15-7:	Precipitation-hardening iron-base alloy containing 15Cr, 7Ni, 2.5Mo and 1Al.
Lapelloy:	Iron-base alloy containing 12Cr, 2.75Mo, and 0.25V.
410:	Iron-base alloy containing 12Cr.

had collapsed during boiler operation, introducing possible flow discontinuities which did not detrimentally affect boiler operation.

The cause of cracks near the end of the inlet plug is obscure at present. The cause of cracks toward the Hg outlet end is apparently a pre-test phenomenon, possibly resulting from cold-draw tooling inadequacies. The cracks at a 5-1/2 in. radius tube bend at the Hg outlet manifold appear to have been caused by a pre-existing, excessively thin tube wall area resulting from tube ID-to-OD eccentricity produced during tube manufacture. This thin wall, combined with external surface decarburization and grain growth, 0.030 in. deep, produced dimetral growth and cracking. Analysis is not sufficiently complete to allow an estimate of the probable life of this boiler had testing continued.

6. Corrosion Loop Program

Additions of mix-4P3E to mercury in scaled boiler loop tests caused degradation of boiler performance. The amount of mix-4P3E that would be necessary to degrade the performance of a full-scale SNAP-8 mercury boiler could not be determined from these tests. Increased liquid velocity in the preheat region of the boiler inlet plug increased the tolerance of the boiler to additions of mix-4P3E. Also, the increased liquid velocity decreased the time necessary for the boiler to regain its thermal performance or condition. These tests indicate that surface contamination of boiler tubing can be a factor in producing poor thermal performance of SNAP-8 types of mercury boilers.

A boiler inlet plug was designed and tested for 359 hr. This plug included the following materials in the preheat section:

Carburized AISI 1020 steel
Dynacut tool steel
Nitrided-Nitralloy
AISI 1020 steel
Tantalum
18-4-1 tool steel
9Cr-1Mo steel

The AISI 1020 steel specimens, completely wetted by mercury, showed the highest corrosion rate. The other iron-based alloys were not wetted by mercury and suffered low corrosion rates. The tantalum section was not attacked by the mercury, indicating that erosion was not the predominant mechanism for loss of material in the preheat section of the boiler inlet plug. Since the entire test section in the boiler inlet plug was not uniformly wetted by mercury, the relative corrosion resistance of some of the materials tested is uncertain.

A program was completed to design and test in corrosion loop 4 (CL-4) a mix-4P3E mercury separator that would prevent mix-4P3E from entering the boiler by removing it from the Hg stream. After preliminary laboratory tests, a gravity type of separator was fabricated and installed in CL-4. With the use of a boiler inlet plug that gave a preheat liquid velocity of 6 fps, a series of mix-4P3E injections was made during loop operation to test the separator effectiveness in a dynamic loop. After each addition of mix-4P3E, no effect was noted on the boiler performance. At the end of the test, the total amount of mix-4P3E added to the loop could not be recovered from the separator. The test performed indicates that a gravity type of separator may sufficiently reduce the amount of mix-4P3E entering the boiler to prevent any impairment of the boiler heat-transfer characteristics, and should be considered for the design of a test-support-equipment separator for the system loops.

Preliminary tests established that <u>in situ</u> X-ray evaluation of the CL-4 boiler Hg tube is feasible. The X-ray source is outside the boiler NaK containment pipe, and the radiographic film is positioned inside the Hg containment tube. The width of the film is such that the film lies flat across the tube ID.

Tests were completed in component test loop 2 (CTL-2) to investigate the effect on boiler performance of adding rubidium to the mercury. A 25-g injection of mix-4P3E deconditioned the CTL-2 boiler, but the addition of Rb (1100 ppm) to the mercury caused boiler reconditioning. Operating time also aided the conditioning process. An effective oxidation method was used to remove Rb from the mercury. The decrease in Rb concentration during the run and the results of the mass balance on the Rb added and extracted from the mercury showed that some Rb was left in the loop.

C. RELIABILITY

1. Reliability Administration and Technical Support

The SNAP-8 reliability effort during the coming report period will be allocated about equally to two general functions (a) reliability administration and technical support, and (b) operations evaluation and failure analysis. Technical support to SNAP-8 Program during the July-December 1966 report period included (a) reliability analysis and comparison of three conceptual designs for the PCS-1/SL-1 Phase II control system (Ref. 46), (b) an analysis of the probability of obtaining three bearing failures on one test machine based on performance history of ten bearings tested on six machines, (c) participation in design and management reviews of PCS-1/SL-1 Phase II, RPL-2, and PCS-1 Phase IV test facilities, (d) comments on content of proposed Project System Specification (PSS) and recommendations for reliability requirements on the Project System Specification for the ground prototype system (GPS), (e) review of design documentation and change control system, (f) consultation on reliability assurance program required for SNAP-8 support work at Aerojet-General Nucleonics, (g) analysis of EM pump performance reliability, and (h) analysis of need for 60 cps standby power to provide continuity of SNAP-8 PCS-1 endurance test operations.

A formal assessment of the reliability demonstrated by major SNAP-8 PCS components was initiated.

2. Operations Evaluation and Failure Analysis

SNAP-8 testing activities at the Von Karman Center were monitored and the necessary analysis, reporting, and corrective action of equipment failures was accomplished. General information on the failures reported during this report period are summarized in Table VII-1, "SNAP-8 Active Failure Report Status."

A new SNAP-8 Test Facility Log was designed and implemented to standardize and improve the quality of SNAP-8 test-area event records. The new log book establishes a fixed format for recording significant events in test-area operations. Organizational and individual responsibilities for making log entries are more explicitly defined in the new procedure. Also, provision is made for utilizing a duplicate tear-out sheet for communicating log book or event information to user personnel on a daily schedule. Periodic audits were made to measure intradivision performance in the maintenance of Test Facility Logs and the timely documentation of failures.

The RPL-2 Event Summary (Ref. 47) was analyzed for significant reliability problems encountered in the operation of RPL-2 test-support equipment. These problems were identified and categorized. The corrective action, completed and/or planned for these problems, was summarized.

Compilation of start-stop times for RPL-2 test facility operations was completed for the period June 1964 through December 1965. The number of unscheduled shutdowns per 100 hours of test operations by month was selected as the primary parameter for monitoring.

Cumulative operating times for major SNAP-8 PCS components were compiled and reported on a monthly basis. The detailed summary provided in Table VII-2 gives operating times for major SNAP-8 components by component unit and covers the period of July 1964 through December 1965.

D. QUALITY ASSURANCE

Quality Assurance activities during the period were based on the SNAP-8 Quality Program Plan (QPP) (Ref. 48). However, the scope of several QA functions described in the QPP was considerably modified to reflect the general objectives of the phase-out program. Some activities such as quality audits, monthly quality status reporting, supplier surveys, training, and inspection engineering were curtailed or discontinued altogether; on the other hand, QA activities pertaining to the mechanical inspection of test support equipment were considerably expanded.

The control of PCS and TSE components to determine conformance to drawings and specifications continued at the same high level of quality assurance as previously. However, operational details of hardware quality control were performed in accordance with the standard AGC Quality Control Instructions Manual, since it was decided that the QPP will not be updated to reflect the reduced scope of the phase-out program.

1. Implementation Documents

To implement the general QA approach described above, a number of policy directives were generated.

a. Quality Assurance characteristics to be incorporated on engineering drawings for TSE and PCS lines and structures were identified. The schematic outline of these guidelines is shown on Table VII-3.

b. The appropriate level of effort to be applied by QA for the control of TSE was selected; this level is identified under the heating of "Job-Shop Inspection" on Table VII-4.

c. Acceptance testing of procured data-gathering TSE at AGC showed a need for improvement in technical coordination among the several activities involved. Table VII-5 represents the flow of communications developed as a result of this improvement effort.

d. Several Quality Control Instruction Supplements (QCIS) were written and updated for the support of the SNAP-8 Program. This includes the following:

QCIS No. 002b dated 4 November 1965	QC Purchase Order Riders, Procedure for Application - SNAP-8 Program
QCIS No. 006a dated 16 July 1965	Implementation of BWR Inspection Requirements - SNAP-8 Program
QCIS No. 008a dated 9 November 1965	Certification of AGC Welders per Specification AGC-14067 - SNAP-8 Program
QCIS No. 009a dated 9 September 1965	Certification of Supplier Welders per Specification AGC-14067 - SNAP-8 Program
QCIS No. 025 dated 8 September 1965	Certification of Fusion Welders
QCIS No. 026 dated 7 October 1965	Certification of Radiographers at Supplier Facilities

e. A revision draft was prepared for the SNAP-8 Quality Program Plan. This draft, dated 1 October 1965, served as reference for the preliminary planning of the PCS-G Project, and it will be used as the basic plan of approach for a future updating of the QPP.

2. QA Review of Drawings and Specifications

The QA review and approval of drawings and specifications continued during this period and, as mentioned previously, was extended to include drawings for mechanical TSE. The general scope of the QA engineering document review is shown on Figure VII-6. The QA recommendations and comments developed as a result of the reviews could be classified into two major categories: improvement of quality criteria to refine limits of acceptability, and adding requirements to more adequately determine the inherent quality of the article.

An example for the former, improvement of quality criteria, was the generation of Dwg 097460, X-ray inspection requirements for the tube-in-tube boiler. High weldment reliability requirements of this complex assembly made it necessary to provide an engineering drawing depicting each welded joint, the desired X-ray beam direction and angulation, and the positioning of the film. These detail requirements provide assurance to the designer that all of the critical welds will be subjected to X-ray examination and the resulting films will be fully traceable for the purpose of subsequent performance evaluations. Figures VII-7 and VII-8 are illustrations of methods used to specify the X-ray topography requirements.

Another example for the improvement of design quality criteria was the QA-recommended change to clean the boiler plug inserts in accordance with Specification AGC-10319 rather than a conventional solvent degreasing method (Specification AGC-46004). This change was predicated on the QA experience that solvent cleaning is not likely to result in a surface that is completely free of hydrocarbons.

Examples for added requirements suggested by QA are the following: X-ray inspection of the boiler plug brazed joints for the attachment of instrumentation leads, and dye-penetrant inspection of the spinning-extruded 347 CRES seal ring in the NaK PMA. This latter control was recommended to detect units with parent metal defects.

QA review of drawings for liquid metal loops and the necessary drawing quality criteria were established prior to PCS-1 Phase IV Step 1 testing and were fully implemented during the loop buildup for Step 2 testing. The quality criteria were coordinated in detail with the designers based on the following considerations:

a. Since the liquid metal joints fabricated for Steps 1 and 2 testing must be able to provide satisfactory service during the 10,000 hour testing planned for Step 3, these welds must meet the high workmanship standards of Specification AGC-10227 and welder qualification Specification AGC-14067.

b. Because of redundancies in TSE joint design, Class 9 of radiographic standard AGC-STD-1151 is sufficient; this requirement was coupled with a dye-penetrant inspection of the finished joint to detect any propagating type defects.

c. The above nondestructive tests required a metal-tag identification of each welded joint with a numerically ascending serial number.

d. Each completed line segment will be cleaned and helium leak tested to a 10^{-7} cc/sec leak rate since the sensitivity limitations of X-ray and dye-penetrant inspection will assure structural integrity but not leak-tightness in liquid metal service.

e. Specific drawing notes will be added to specify the slope and low point of lines in addition to the isometric expansion joint configuration.

f. Traceability requirements for materials critical in liquid metal service will be identified on the face of the drawings.

The pre-planning of QA drawing requirements proved to be very satisfactory since this made it possible to process approximately 50 line segment drawings through QA without any significant delays or disagreements.

A major area of QA document review effort is the coordination of PCS component specifications and acceptance test standards. Each of the documents listed in Section VII,E of this report is coordinated with QA prior to release. The basic purpose is to provide a Quality Assurance section in each specification and standard that will describe the elements of control necessary to measure realization against the technical requirements. Specifically, the following questions are reviewed: (a) are preoperational approvals of capability necessary, (b) what in-process controls are necessary, (c) inspection of the product for final acceptance, and (d) documentation to be generated. All of the above provisions must be directly related to the technical requirements.

During the reporting period, increased emphasis was placed by QA on a clear and explicit realization of the above objectives, and action was initiated to amend three key SNAP-8 specifications accordingly. These were AGC-10227 Fusion Welding, AGC-10336 Clean Room Operating Procedure, and AGC-10319 Cleaning Methods.

3. Control of Procured Materials

The QA control of procured materials was characterized, as previously, by the selective application of QA requirements to the AGC-supplier purchase agreement. This resulted in wide range of QA provisions, varying from simple AGC receiving inspection to full supplier quality program review. In a few instances, as for the tube-in-tube boiler and for pressure transducers, this included the on-site evaluation of the supplier's implementation of Aerojet quality requirements and a joint Aerojet engineering and QA effort to resolve problems.

In the case of the tube-in-tube boiler, Aerojet Quality Engineering assisted the supplier to prepare an Inspection Flow Plan that identified closure welds, and to evaluate X-ray films of all previous welds at these points in the fabrication process to avoid costly reoperation after the closure weld has been completed. In the case of pressure transducers, Aerojet receiving inspection testing revealed leakage as well as unacceptable variations in the electrical output signal. To correct these problems, an on-site evaluation of the supplier's facility was made and the retest of the unacceptable units was witnessed.

As a result, improvements were made in the Aerojet and supplier test procedures and action was initiated to formalize the test requirements as an AGC Standard document. In addition, the sequencing and method of supplier helium leak testing was found to be unsatisfactory; the supplier used the probe method per MIL-STD-271 and this was followed by still another fabrication operation. Since the probe method under these circumstances could not indicate the total leak rate of the delivered unit, the supplier was redirected to utilize the hood method as the last operation prior to packaging and shipment.

To avoid the necessity of repeating calibration tests at Aerojet, and yet to assure the procurement of high-quality products, source acceptance by Aerojet Supplier Quality representatives was added to the purchase agreement. This obligates the supplier to present each lot of completed units to the Aerojet QA representative who will select at random one unit for a complete retest and verification of supplier test results.

To include the appropriate QA provisions in each of the purchase agreements, each Stores and Purchase Requisitions (SAPR) was reviewed and the necessary quality control requirements were added. A summary of the SAPR review activity is presented as Figure VII-9. When the QA requirements are too voluminous to be entered on the Purchase Order, they are listed on a separate document referenced on the P.O.

In addition to the transducer order discussed previously, Aerojet Supplier Quality representatives monitored turbine components and the fabrication of the tube-in-tube boiler. Particular emphasis was placed on the monitoring of critical special processes such as resin removal after tube bending, cleaning, and final leak testing. As mentioned previously, all X-ray films were evaluated on-site before the supplier was permitted to proceed to the next closure weld in the fabrication process.

Receiving inspection of SNAP-8 materials and components was performed in accordance with instructions entered or referenced on the Purchase Order in response to Quality Engineering requirements. A graph illustrating the average receiving inspection acceptance rate (approximately 95%) and the quantity of articles inspected each month is shown in Figure VII-10.

Laboratory testing of purchased materials was limited to the receiving testing of data-gathering equipment such as transducers. In addition to the specific supplier test improvement program described previously, tests of variable-reluctance pressure transducers revealed questionable functional characteristics of the particular design involved. These and test performance problems contributed to the initiation of better Aerojet controls, such as the preparation of AGC Standard designs with companion approved Supplier Lists and Acceptance Test Standards. Another benefit was the overall clarification of responsibilities for technical communications.

4. Control of Aerojet Fabricated Materials

All Shop Orders (SO), except those issued to electrical laboratories, were reviewed by Quality Engineering and inspection requirements were incorporated. The number of SOs processed is shown on Figure VII-11, involving all the components listed under Section VI of this report except some of the experimental model electrical controls.

The typical QA requirements integrated into SOs involve the following elements: (a) verification of materials and components used for identification, traceability and prior inspection acceptance, (b) inprocess inspection of those characteristics that cannot be checked on the finished product, (c) special process control and nondestructive testing, (d) final inspection for critical and major characteristics, and (e) documentation of inspection results.

During the reporting period, an intensive coordination effort was made with the PCS-1 Project groups to initiate and to maintain an integrated SO system in the test areas. Particular emphasis was placed on the correct division of responsibilities between test operations and QA to avoid costly duplication of efforts. An outline of the steps and controls required for making a liquid metal pipe weld was prepared.

As stated previously, all welds made in liquid metal lines during the period were subjected to X-ray inspection. The decision to inspect each weld was based on an evaluation of actual inspection results obtained from the Phase I buildup of SL-1 during the period of June 1964 through January 1965. A review of these data and conclusions derived indicate that approximately 20% of welds made under partially controlled conditions did not meet drawing requirements, while welds made in accordance with the steps and controls prepared by QA resulted in a better than 98% conformance without any repair or reoperation (Figure VII-12).

The above rather startling improvement can be attributed to the following factors:

a. Improvements in welder prequalification requirements and performance controls as reflected in AGC-14067 Rev. "C" Amend. 2.

b. Improved operational controls.

c. Welder motivation developed from the results of 100% radiographic inspection.

Several PCS components were delivered to NASA during the reporting period. In each case Aerojet and Government inspection was accomplished in accordance with Quality Engineering instructions without any significant nonconformances. Specific shipping inspection instructions were generated for each deliverable item as follows: Speed Control Stabilization Transformer (QE 851-1149), Auxiliary Start Loop Heat Exchanger (QE 851-1144), Turbine Spare Parts (QE 851-1156), Thermocouples (QE 851-1166), Hg Injection System (QE 851-1167) and NaK Pump Motor Assemblies (QE 851-1168).

Inspection in fabrication and assembly shops, including the SNAP-8 clean room, was accomplished in accordance with integrated Shop Orders and/or separate inspection instructions. The results of these inspections are shown on Figure VII-13.

5. Nonconforming Materials

In accordance with the SNAP-8 Quality Program Plan, nonconforming materials were reported on supplier or Aerojet inspection reports and subsequently dispositioned by an engineering review board.

Table VII-6 shows the causes of nonconformances and the number of occurrences in each category.

Table VII-7 is a review of the more significant nonconformances, interpretation of inspection results obtained, and summary of further action taken to prevent recurrence.

6. Control of Measuring and Test Equipment

Calibration of measuring and test equipment continued in accordance with the requirements of the Standard AGC Quality Control Instruction

Manual and its supplements. This system includes the utilization of electronic data processing equipment for providing calibration recall notifications and calibration delinquency notices to each user of data gathering equipment.

During the reporting period, a major effort was initiated to update the computer input from the standpoint of SNAP-8 user designation by section number, and the incorporation of correct calibration status information. This effort is still in process because of the numerous changes made as a result of PCS-1 Phase II and Phase IV reprograming; however, the calibration accuracies of operational equipment were maintained throughout the period by means of date-marked calibration stickers displayed on each piece of equipment.

Aerojet calibration laboratories are establishing a central exchange pool for standard portable equipment. This improvement found little application to the SNAP-8 Program because of reprograming changes, but it is expected to be more helpful in the future in reducing the time element involved in recalibrations.

7. Certification Control Center Activities

The Certification Control Center maintained cognizance over the following special skills and capabilities:

a. Aerojet welders qualified in accordance with AGC-14067 were monitored for continued high level of workmanship on a monthly basis, using a summary of weld quality.

b. Supplier welders qualified in accordance with AGC-14067 were monitored by Supplier Quality Representatives.

c. Aerojet nondestructive test inspectors were certified.

d. Supplier radiographic readers were certified and their performance continually evaluated by rereading of films by Aerojet Quality Engineering.

Eight supplier calibration laboratories were reevaluated during the period to provide approved supplier lists. Approved calibration suppliers are indicated for each transducer that utilizes an Aerojet standard design.

Special process suppliers (e.g., the supplier for the cleaning of the tube-in-tube boiler) were evaluated and approved as to their capability to comply with Aerojet requirements.

8. Data Reporting and Corrective Action

Quality Assurance continued to prepare Buildup and Assembly Logs for all major PCS components. These logs provide traceability, change control, and nonconformance information at the first-tier subassembly level; further traceability back to the Aerojet receiving inspection is assured by supporting computer programs.

The effectiveness of the Aerojet defect reduction program was monitored and reported monthly. Specifically, the efforts to correctly identify the cause of each discrepancy, to identify the organization responsible for the discrepancy, and the development of a meaningful preventive action were reviewed each month. The results were computed in percentages. At the close of the period, the above efforts were rated as 86% and 90% effective for procured and for in-plant fabricated materials.

A separate Part History Card for each SNAP-8 part of component is being maintained. These cards provide the complete part quality history for use by the Engineering Review Board when reviewing nonconformance reports. The Part History Cards were also utilized to compile monthly summaries of inspection results.

9. Quality Audits Performed

Regularly scheduled SNAP-8 Quality Audits were discontinued for the phase-out program. However, one special audit was performed in August to check compliance with integrated Shop Order instructions in the SL-1 test loop buildup area. Audit Report No. 282 dated 25 May 1965 revealed a number of noncritical deficiencies which were brought to the attention of the responsible engineers. The effectiveness of corrective measures taken could not be evaluated due to the subsequent discontinuation of PCS-1 Phase II test preparations.

In addition to the above special quality audit, the SNAP-8 Quality Program was included in general Von Karman Center facility-wide quality audits that checked the effectiveness of the overall Quality Assurance system. No significant discrepancies were reported as a result of these audits.

E. SPECIFICATIONS AND STANDARDS

1. Documentation Control

A documentation control plan was established that provides for the organization and control of all necessary design documents for the PCS-1 Phase IV project. The basis of this plan was the establishment of a complete parts list of the system and a reorganization of the design disclosure documents into the Aerojet-General Corporation standard numbering system. Progress to date has been steadily increasing. A specifications and standards file to support the SNAP-8 Program was established for the following PCS-1 Phase IV design documentation:

Assembly drawings and lower-tier detail drawings
Interface and correlation drawings
Design and part standards
Equipment, component, and material specifications
Process specifications
Book standards
Assembly and inspection procedures
Acceptance test procedures
Design parts list

Plans are being generated to organize the PCS-G documentation system. This system will follow the Aerojet controlled documentation system, but will utilize the specification formats in NASA Configuration Management Manual, NPC 500-1.

2. Released Specifications and Standards

Since June 1965, 18 process and assembly procedures, 6 acceptance test procedures, 12 component specifications, 2 material specifications, and 3 part standards were released.

3. Documentation in Process

Work is continuing with the updating of cleaning specification AGC-10319 and its 14 associated detail cleaning procedures. Completion is expected by the end of February. A final draft of the mercury flow control valve, component specification AGC-10414, is being reviewed for release. Acceptance test procedures for the transformer reactor assembly (AGC-STD-1242) and low-temperature control assembly (AGC-STD-1243) are being updated. The tube bending procedure, AGC-STD-1273, is being updated to include provision for using tree resin as a filler during the bending process. The Boiler Quality Conformance Inspection Procedure, AGC-STD-1289, is being reviewed for final modifications so that it may be implemented at Von Karman Center upon delivery of the boiler. Work is in process on five detailed test procedures for pressure transducers (AGC-STD-1288, Methods 10, 11, 12, 13, and 14) and seven detailed test procedures for electrical transducers (AGC-STD-1287, Methods 10 through 16). Differential pressure transducer sheet standard AS8029 is being reviewed for release. The clean room specification, AGC-10336B, is being reviewed for final recommendations necessary for certification of the clean room.

4. PCS-1 Phase IV Engineering Parts List

An engineering parts list for the major components through the second tier of PCS-1 Phase IV was IBM key punched and issued in November 1965. This list is now being updated to provide an indentured parts list exploded to the last tier for the components. The next issue shall also include the first tier parts list of the Test Support Equipment and the first tier parts list of the instrumentation. This IBM key punched engineering parts list will include all drawings, part standards, design standards, commercial part numbers, and specifications listed on each drawing. The parts list should be completed by 15 March 1966.

TABLE VII-1

SNAP-8 ACTIVE FAILURE REPORT STATUS

Period Covered: 1-65 Through 12-65
Date of Last Report: 9-1-65

Date of Failure	Failure Report No.	Failed Part Name and Number	Description of Failure	Failure Classif.	Failure Analysis Required	Status/Remarks
1-6-65	1211	Mounting Clamp No. MBC 605220 L/C PMA 253800-3 S/N 48505 (TRW)	During L/C PMA environmental test, resonance frequency scan, the motor end mounting clamp broke.	Minor (PCS)	Yes	All units have new clamp design incorporated. Rerun of vibration test required to verify problem corrected.
2-4-65	0882	NaK PMA No. 093200-1 S/N A-1	Pump failed to restart after shutdown and ~51 hr. operation in LNL-3 loop. Pump casting leak was also noted.	Major (PCS)	Yes	See TM 4932:65-1-034. Latest design PMA satisfactorily completed 3000 hr. endurance test. Case considered closed.
2-16-65	1230	EM Pump 501014	RPL-2 Primary NaK Syst. pump leaked at inlet of pump tube adjacent to buss bar.	Incid (TSE)	No	Vendor's evaluation and report indicate gas entrapped in loop to be cause of failure. Improved loop and pump operating procedure implemented to preclude gas entrapment. Case considered closed.
3-2-65	1220	NaK PMA 093200-13A S/N A-1	After 31 hr. of testing in LNL-3, NaK leaks were noted from pump discharge, welded conoseal and from pump casting body.	Major (PCS)	Yes	See Remarks for RFR 0882. Case considered closed.
3-14-65	1213	Bellows Assy. Liftoff Seal MPMA 094872 S/N A-1 MBC Part No. 56164.	MPMA Lift-off Seal Assy failure during testing in RPL-2 resulting in loss of Hg inventory to space.	Minor	Yes	Metal Bellows Corp. Failure Analysis Report No. CR 37 dated 4 Oct. 65 reviewed. Conclusion reached by vendor not concurred with by AGC. New proposed bellows design being evaluated. Ref. Aerojet letter No. 4932:65-156 dated 12 Nov. 65. Continued follow-up required.

SNAP-8 ACTIVE FAILURE REPORT STATUS (cont)

Date of Failure	Failure Report No.	Failed Part Name and Number	Description of Failure	Failure Classif.	Failure Analysis Required	Status/Remarks
3-29-65	0505	NaK PMA 093200-13 S/N A-2	Small NaK leak from pump casting, testing continued with temporary repair. Facility power failure shut down loop and pump could not be restarted after 194 hr. of testing in LNL-3.	Major (PCS)	Yes	Case considered closed. See Remarks for RFR No. 0882.
4-27-65	1534	HRP-1 Chempump No. GET 15K-34-35 S/N 13083-1	SL-1, HR Loop Chempump froze up after approx. 4 sec. of operation. Restart attempts indicated no rotation.	Incid (TSE)	No	See TM No. 4932:65-1-328 dated Nov. 3, 1965 for results of investigation and analysis. Recommended Chempumps not to be used for SNAP-8 test application until improved design and quality can be established. Case considered closed.
5-4-65	1535	HRP-1 Chempump No. GET 7 1/2 K 25-25-35 S/N 13039-1	During SL-1 test operation the HR loop chempump circuit opened by the thermo cutout circuit. Restart attempts were not successful.	Incid (TSE)	No	See Remarks for FR No. 1534. Case considered closed.
5-23-65	1238	MPMA Liftoff Seal Bellows Assy MBC No. 56164 MPMA No. 094872	During startup of Hg loop in RPL-2, excessive Hg noticed in space seal drain trap (210 lbs) indicating bellows failure.	Minor (PCS)	Yes	See Remarks for FR No. 1213. Continued follow-up required.
6-10-65	0139	SL-1, RSP-1 Chempump P/N GD5K-152-1T, S/N 13116-1	During SL-1 test operation RS Loop Chempump circuit opened by thermo cutoff circuit. Pump would not restart. Noted that RS Loop fin fan cooler not on during operation.	Incid (TSE)	No	See Remarks for FR 1534. Case considered closed.

SNAP-8 ACTIVE FAILURE REPORT STATUS (cont)

Date of Failure	Failure Report No.	Failed Part Name and Number	Description of Failure	Failure Classif.	Failure Analysis Required	Status/Remarks
6-11-65	0126	SV-4 L/C Solenoid Valve No. 54600-04 S/N 12	During MPMA Startup in SL-1 Facility, Lube Coolant valve SV-4 did not open when control switch was operated. Resulted in flooding of MPMA space seal area and vacuum lines with L/C fluid.	Minor (PCS)	No	For results of investigation by component design, see Memo 4932:65-107 dated 7 August 1965. Cause of failure--operation error. Case considered closed.
6-17-65	0101	EM Pump No. 501014 S/N 565	RPL-2 Heat Rej. Loop EM pump circuit breaker opened shutting down the loop. Pump coil shorted out by NaK, leaking from inlet end of pump tube near buss bar attachment. Tube fractured (fatigue type).	Incid (TSE)	No	Vendor's analysis complete. MSA Letter Report dated 17 Sept. 1965. Fatigue type fracture caused by excessive magnetostriative forces. We now know Style VIII pump should not be used in low temp. systems. Case considered closed.
6-22-65	0103	Turbine Alternator Assy P/N 093000-5 S/N A-3	Approximately 2 min. after startup in RPL-2 facility the TAA came to an abrupt halt. Turbine assy failure.	Major (PCS)	Yes	Failure Analysis and Report complete. See TM 4932:65-5-332 dated 14 Oct 65. A new TAA (Ser. No. A-2) incorporating several major design changes, was installed in PCS-1 Phase IV facility. Scheduled for testing 2-66. Follow-up required for adequacy of corrective action.
7-14-65	0136	SV-3, L/C Valve P/N V-54600-04	L/C supply valve to MPMA failed to close on demand during a normal SL-1 system shutdown resulting in flooding of MPMA space seal cavity and vacuum system.	Minor (PCS)	No	See Memo No. 4932:65-107 dated 7 Aug 1965 for results of investigation by component design. Probable cause of failure: Hi temp-environment. Air cooling eliminated problem. Case considered closed.

SNAP-8 ACTIVE FAILURE REPORT STATUS (cont)

Date of Failure	Failure Report No.	Failed Part Name and Number	Description of Failure	Failure Classif.	Failure Analysis Required	Status/Remarks
7-21-65	0135	RSP-2 Chempump P/N GD5K-152-2T S/N 13116-2	During SL-1 Hg Loop shutdown the radiator simulation loop chem-pump stopped when current went up to 40 amps and thermo switch opened circuit. Pump would not restart after cooldown.	Incid (TSE)	No	See TM No. 4932:65-1-328 dated Nov. 3 1965. Ref. FR No. 1534 for other comments. Case considered closed.
8-25-65	0110	RPL-2 Condenser P/N 092500-1	During RPL-2 modification the NaK side of the condenser was accidentally penetrated while removing lower end, Hg side, of condenser to check Hg tube plugging.	Minor (PCS)	No	Condenser repaired and modified per V.E.O. No. 2392. Retested 12-65, performance improved. Case considered closed.
9-9-65	0144	PNL EM Pump NASA No. 55 S/N 540	SL-1 Primary NaK EM pump developed a leak at the inlet end of the pump tube adjacent to buss bar attachment.	Incid (TSE)	No	MSA Analysis reports failure was result of operating pump with air in system. See AGC Memo 4943-65-0070 dated 15 Oct. 1965. Case considered closed.
9-21-65	0027	Tube in Tube Boiler P/N 097444-5 S/N A-1	During SL-1 boiler test smoke was noted from area of boiler NaK outlet tee on 9-18-65. Failed area appeared to be a small materials flaw approximately 1/4" from NaK tube weld joint.	Minor (PCS)	No	Boiler repaired per VEO No. 2348. SL-1 mothballed 12-65. No further action planned at this time.

SNAP-8 ACTIVE FAILURE REPORT STATUS (cont)

Date of Failure	Failure Report No.	Failed Part Name and Number	Description of Failure	Failure Classif.	Failure Analysis Required	Status/Remarks
10-22-65	0404	L/C Syst. Water Heat Exchanger	Unable to maintain proper L/C system temperature. Found water type heat exchanger plugged with gray-white material, probably calcium magnesium salts.	Incid (TSE)	No	Cleaned out heat exchanger. Relocated water control valve to outlet side of heat exchanger from inlet side. No further problems. Case considered closed.
10-22-65	0146	L/C Syst. Check Valve 259T-16TT S/N 1715 (SNAP-8)	During SL-1 L/C loop checks, found TSE check valve in series with SV-4 valve and leaking past seat. Investigation showed Buna-N type O-ring used in check valve had displaced and prevented check valve from seating. Buna-N type material not compatible with 4P3E fluid.	Incid (TSE)	No	Failed check valve replaced with new check valve equipped with non-elastimer type seal. Problem has not reoccurred. Case considered closed.
10-22-65	0150	HRP-1 Electrical Cables SL-1	HR Loop EM pump leads shorted to pump protective cage at cage cutcut for cables. Pump vibration wore away cable insulation. Inadequate cable support and insulation cause of failure.	Incid (TSE)	No	Replaced damaged cables. Installed cable support at cage cutout and insulated with proper insulation. Case considered closed.

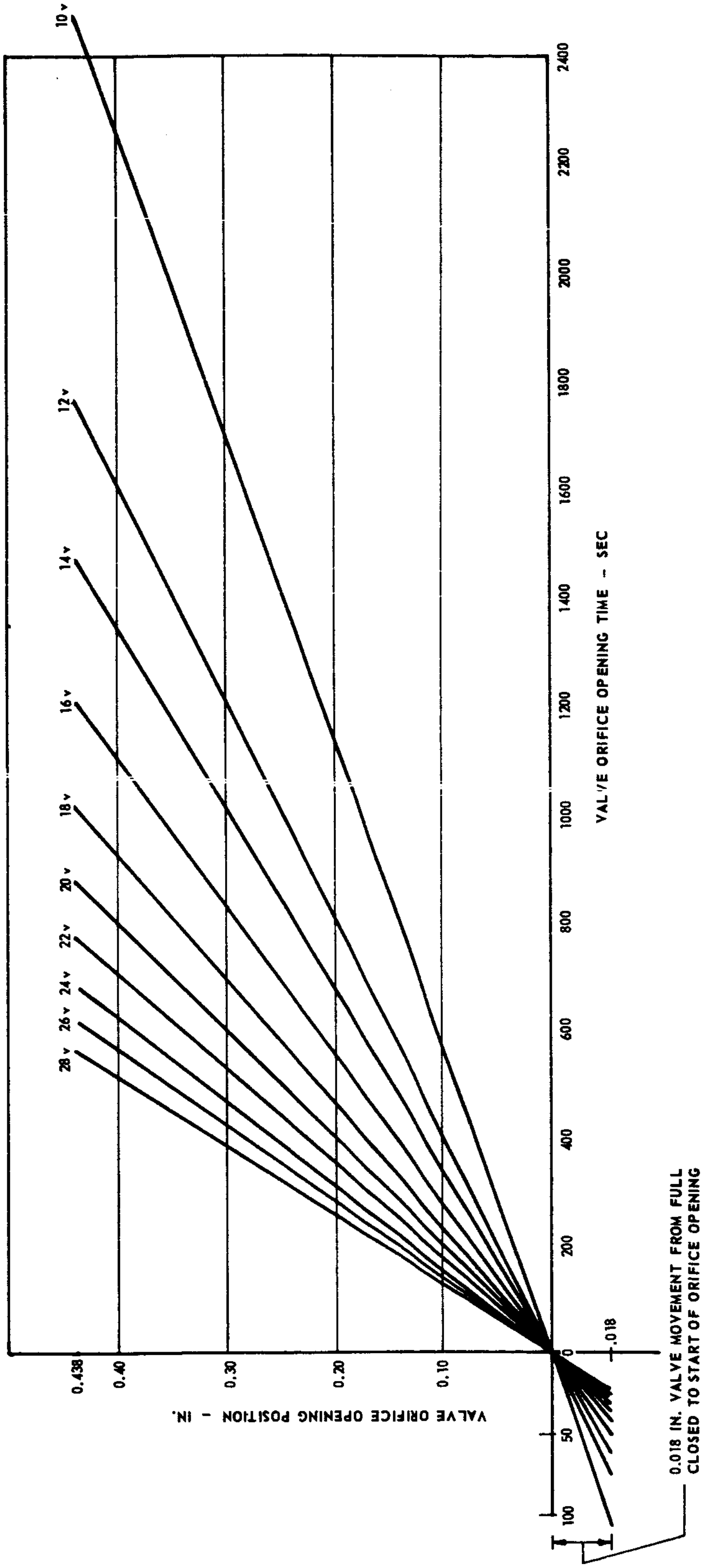
SNAP-8 ACTIVE FAILURE REPORT STATUS (cont)

Date of Failure	Failure Report No.	Failed Part Name and Number	Description of Failure.	Failure Classif.	Failure Analysis Required	Status/Remarks
11-8-65	0141	HRP-1 EM Pump P/N 5010104 S/N 651 NASA No. 1256 SL-1	During restart of EM pump a fire was noted near EM pump at power leads. One electrical power lead was burned in two at connecting joint. One of the EM pump field coils was grounded, the circuit through the coil was open and small drops of copper were found at base of the coil. Erratic operation history on pump.	Incid (TSE)	No	See AGC Memo No. 4931-65-0066 dated 16 Nov. 1965. Insulation failure of field coil was probable cause of failure. Pump returned to vendor for repair and modification to Style VII pump. Case considered closed.
11-28-65	0123	L/C Loop Clamshell Heater Assy. AGC PCS-1 Ph IV Step 1	RPL-2 L/C Loop clamshell heater assy. glass tape insulation on power leads melted and shorted to adjacent tubing and burned holes in tubing.	Incid (TSE)	No	Replaced heater assy, repaired pipe and installed ceramic bead type insulation on power leads in high temp areas. Case considered closed.
11-30-65	0114	T-T Boiler Plugs (7) Dwg 098460 S/N A-1 PCS-1 Ph IV Step 1	On initial operation development test of T-T boiler a severe restriction of Mercury flow rate prevented continued testing. Further investigation revealed suppressed boiler occurring at boiler inlet due to tight pitch in spiral turns of boiler plugs.	Minor (PCS)	No	Spare set of plugs P/N 097892-1 were modified per VEO 0729 and installed in T in T Boiler P/N 097444-7 per VEO 0730. Boiler testing has been satisfactorily completed with these plugs. Case considered complete.

SNAP-8 ACTIVE FAILURE REPORT STATUS (cont)

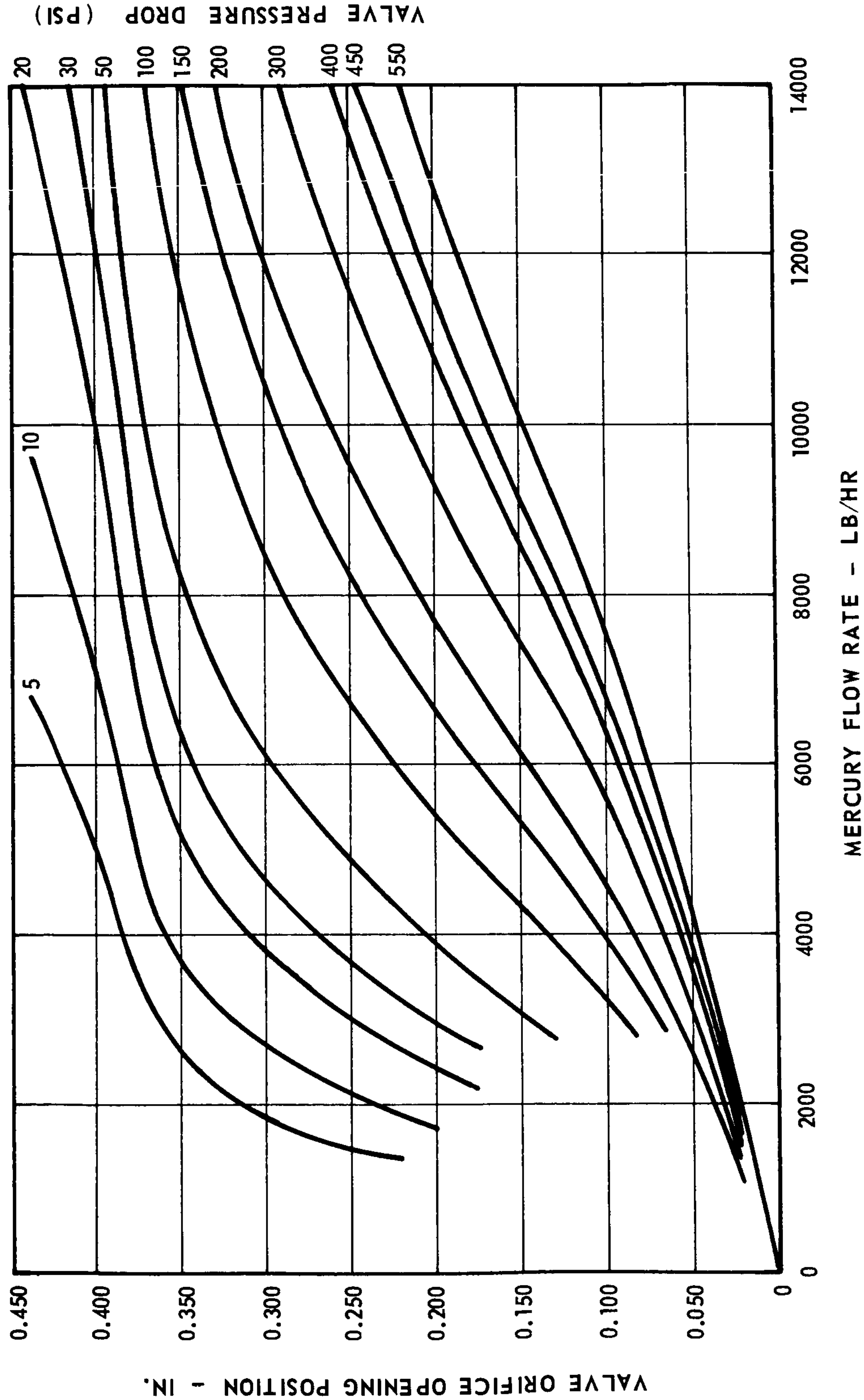
Date of Failure	Failure Report No.	Failed Part Name and Number	Description of Failure	Failure Classif.	Failure Analysis Required	Status/Remarks
12-1-65	0115	Hg Flowmeter Instr. Line P and I 098709 PCS-1 Ph IV Step 1	D-3-Z-47 post test inspection found small Hg leak at weld of instrumentation tubing for Hg liquid flowmeter ΔP 276 transducer.	Incid (TSE)	No	Bad weld was repaired in place and leak check made. Follow-on testing showed repair satisfactory. Case considered closed.
12-6-65	0120	HgV-6 Pneumatic Valve P and I 098709 PCS-1 Ph IV Step 1	Lost Hg inventory during test run D-3-Z-49 causing loop to be shut down (See FR 0124). Post checks showed HgV-6 Hg emergency dump valve to be leaking past seat.	Incid (TSE)	No	Valve disassembled and repaired in place and leak checked OK. Follow-on testing showed repair satisfactory. Case considered closed.
12-6-65	0124	HgV-1 Aveco Control Valve Ser. No. 34 PCS-1 Ph IV Step 1	RPL-2 Hg Loop shut down due to loss of Hg inventory. Post operation checks showed leak past valve seat. Foreign metal particles imbedded in valve seat.	Incid (TSE)	No	Replaced damaged valve with similar valve. Case considered closed.
12-9-65	0121	Swagelok Union 3/4" (MPMA discharge) P/N 1210-2-12-316 PCS-1 Ph IV Step 1	Small Hg leak noted during test run D-3-Z-50 from Hg PMA outlet line. Did not require loop shutdown.	Incid (TSE)	No	Swagelok fittings retorqued after loop shutdown. Monitor during next test operation (Step 2).

A366-NF-1133



Actuation Characteristics of Mercury Flow Control Valve
Valcor Valve S/N A-2

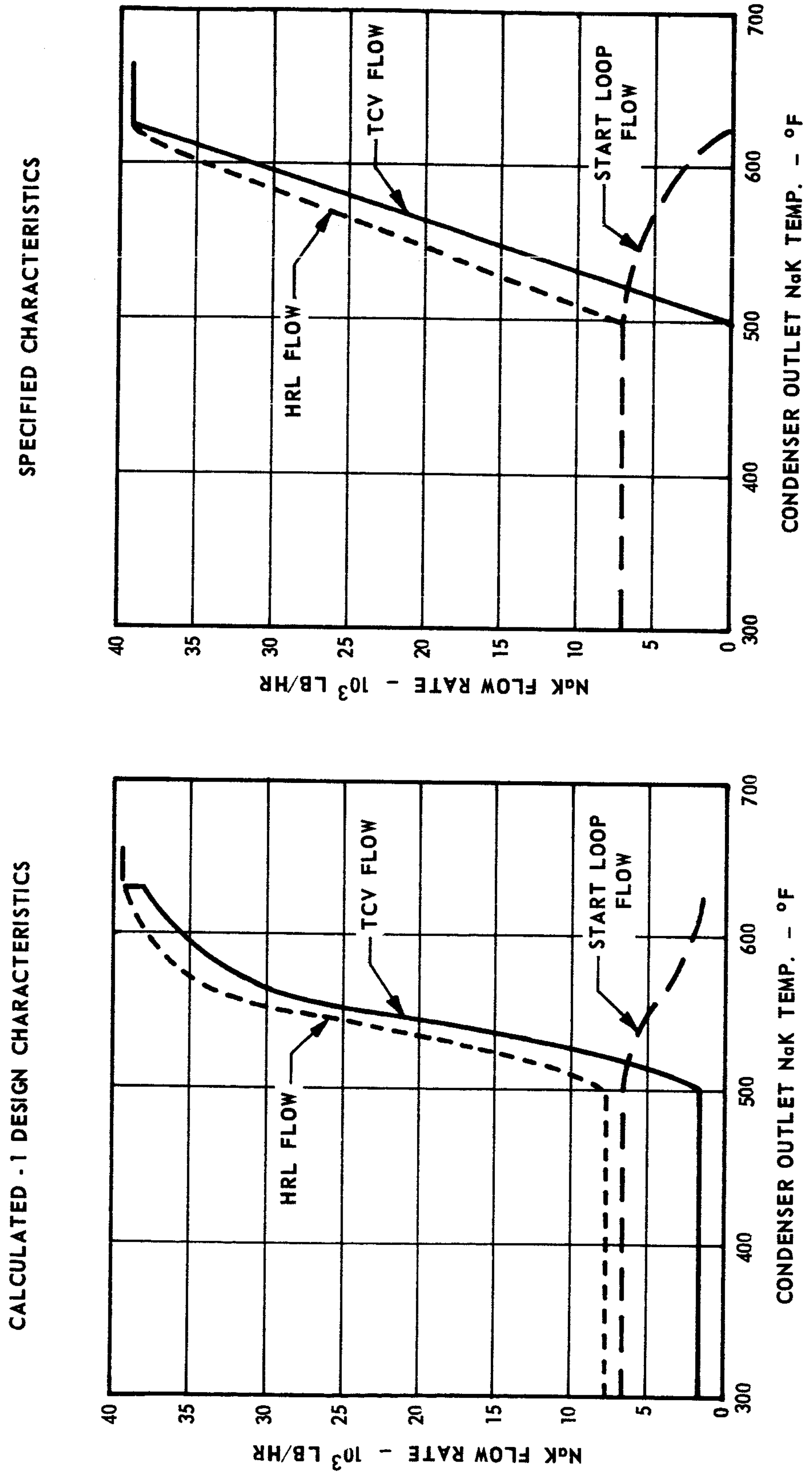
Figure VII-1



Mercury Flow Control Valve Characteristics for Valcor Valve in PCS-1

A366-NF-1134

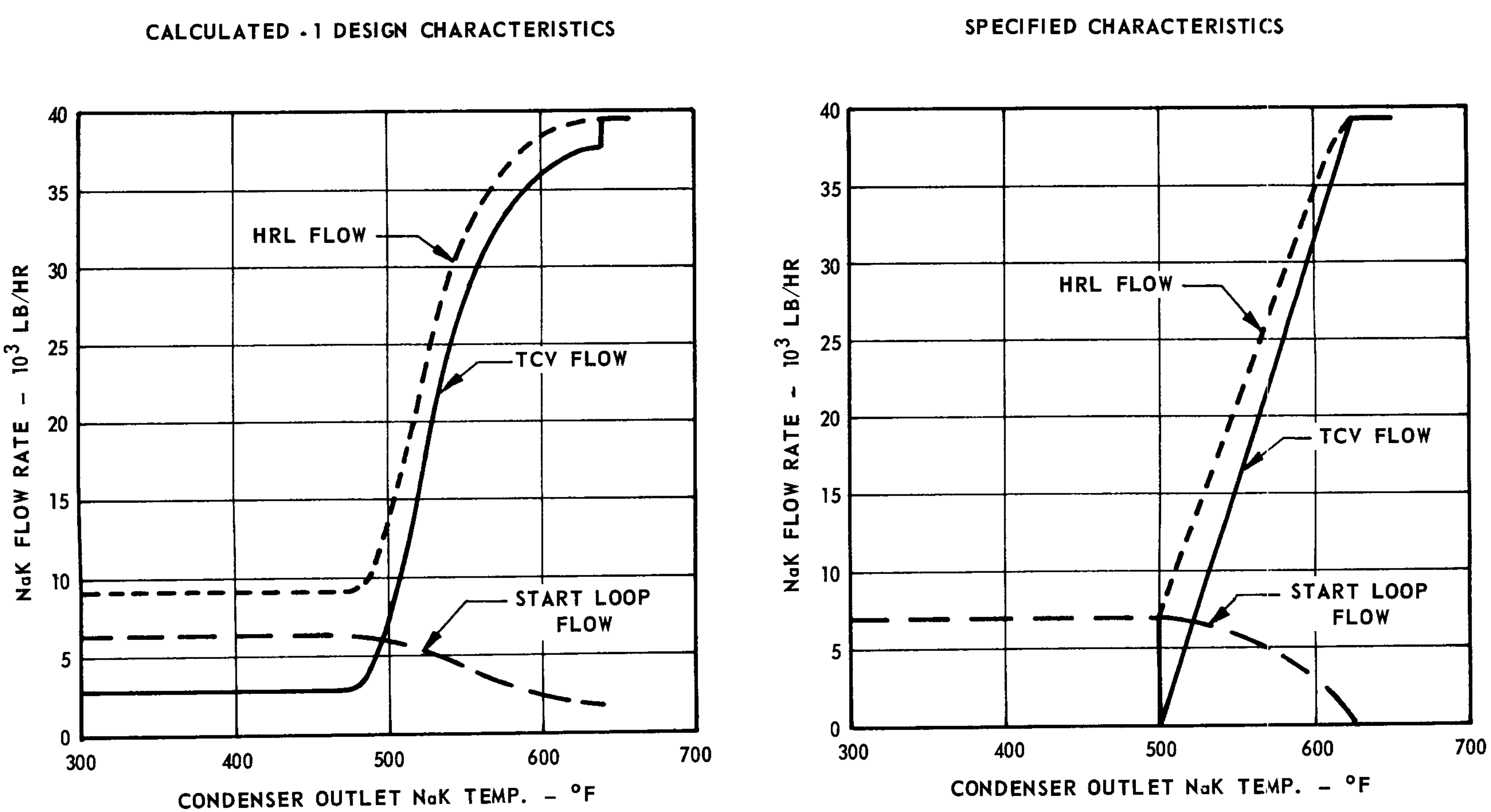
Figure VII-2



Comparison of Calculated -1 Design with Specified
Temperature Control Valve and Heat Rejection Loop Characteristics
Roylyn Valve S/N 001

A366-NF-1135

A366-NF-1136



Comparison of Calculated -1 Design with Specified
Temperature Control Valve and Heat Rejection Loop Characteristics
Roylyn Valve S/N 002

SNAP-8 EGS Performance Ba
Upper Temperatu

PCS POWER BALANCE

HRL Radiator		444.0 kw_t
L/C Radiator		22.2
Line and Component Losses	Pri.	6.0
	Hg.	1.0
Electrical Power to Vehicle		35.5
		508.7

ELECTRICAL POWER BALANCE

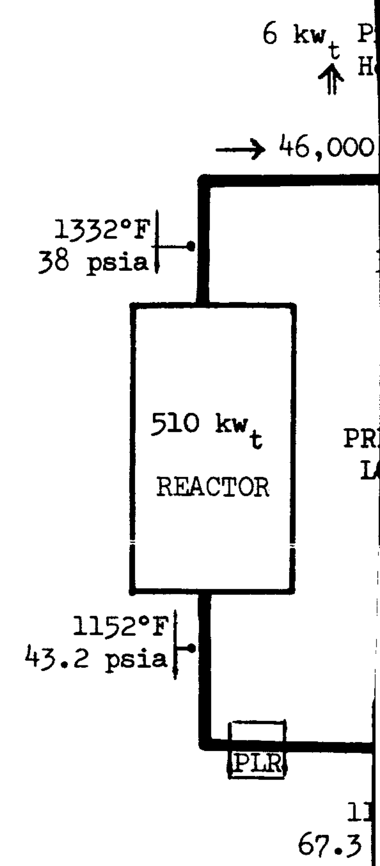
Alternator Output		54.0 kw_e
Loads		
Vehicle Load		35.5
PCS Controls		1.0
Parasitic Load:	Min. Resid.	1.5
	Pwr. Stability	3.0
PN-PMA		4.3
HRL-PMA		4.4
MPMA		2.86
L/C - PMA		1.43
		53.99

TAA PERFORMANCE

Turbine Power	66.0 kw_t
TA Seal and Bearing Loss	3.3 kw
Turbine Efficiency	55.5 %
Alternator Efficiency	86 %

SYSTEM PERFORMANCE

Reactor Power (to PCS)	510 kw_t
System Efficiency	6.9 %



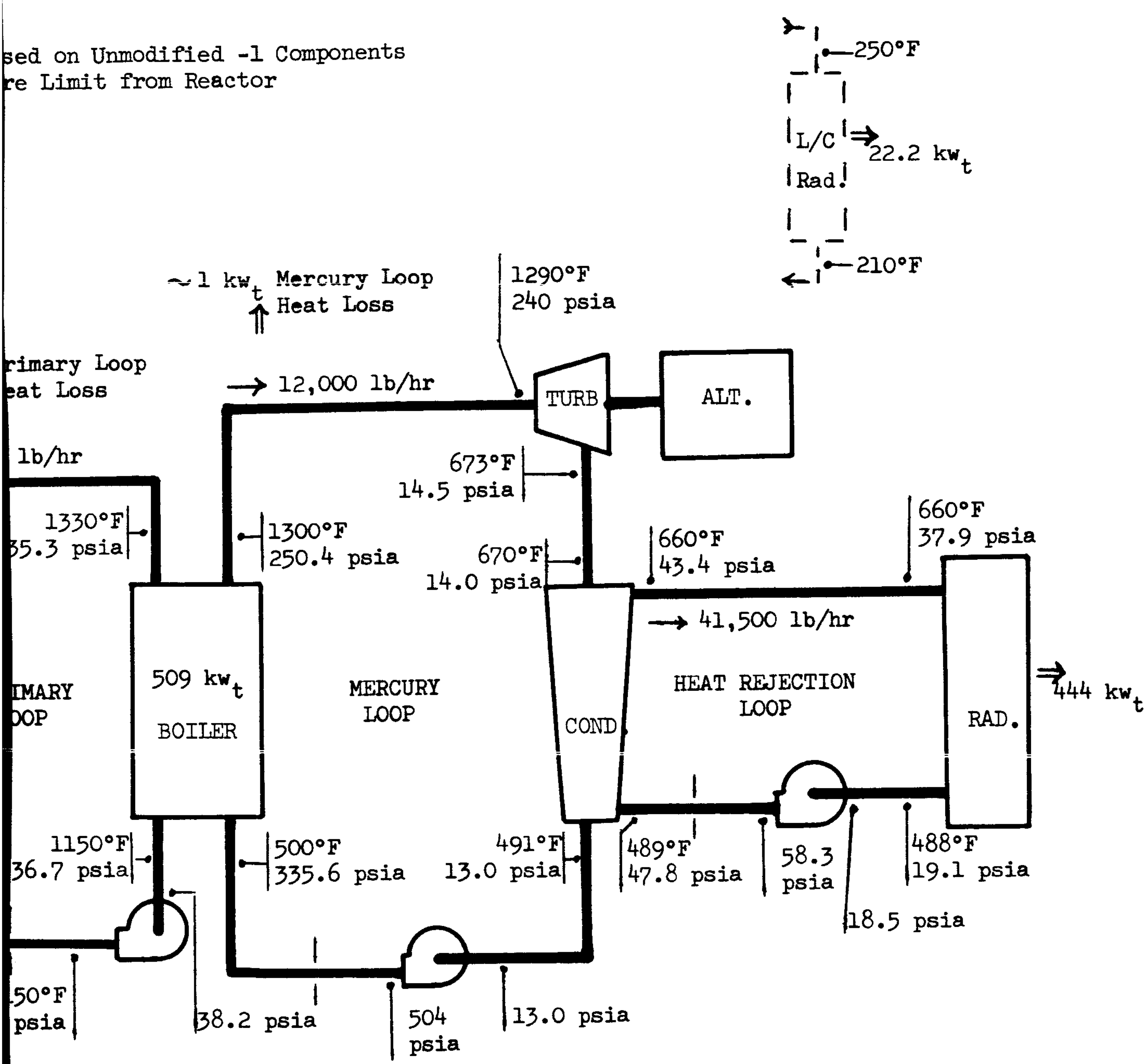
Notes:

1. Performance shown
of unmodified -1
to July 1965. Tu
in process are no
not the reference

2. Boiler performanc
design.

III-5.1

sed on Unmodified -1 Components
re Limit from Reactor



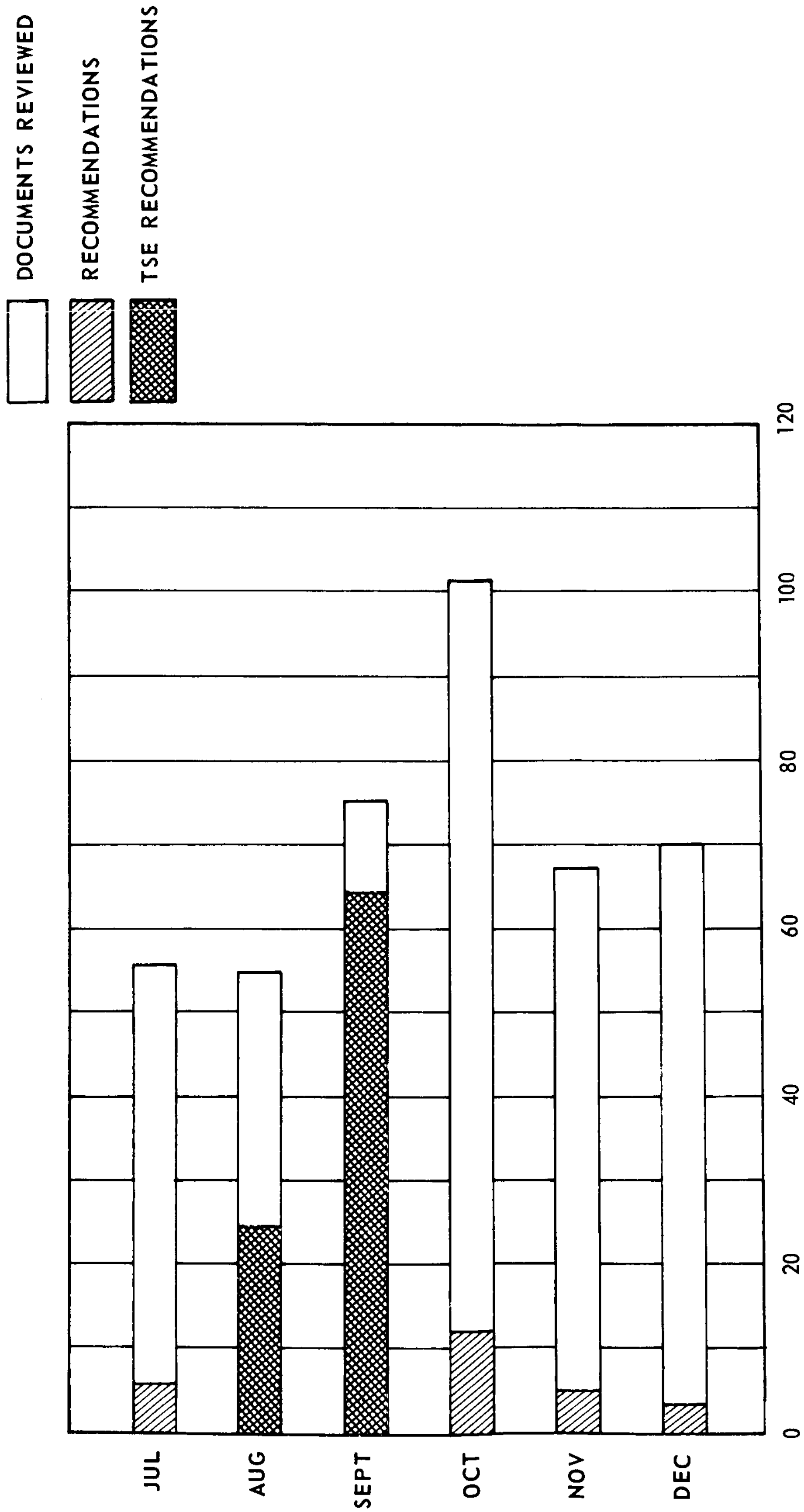
is based on test results
omponents obtained prior
bine design changes now
accounted for. This is
system.

based on tube-in-tube

3. Boiler liquid carryover of 2% is assumed.

4. Operation in 300 nmi earth orbit with maximum sun and earth heat load is assumed.

Figure VII-5 2



Drawings Reviewed for Quality Requirement Integration

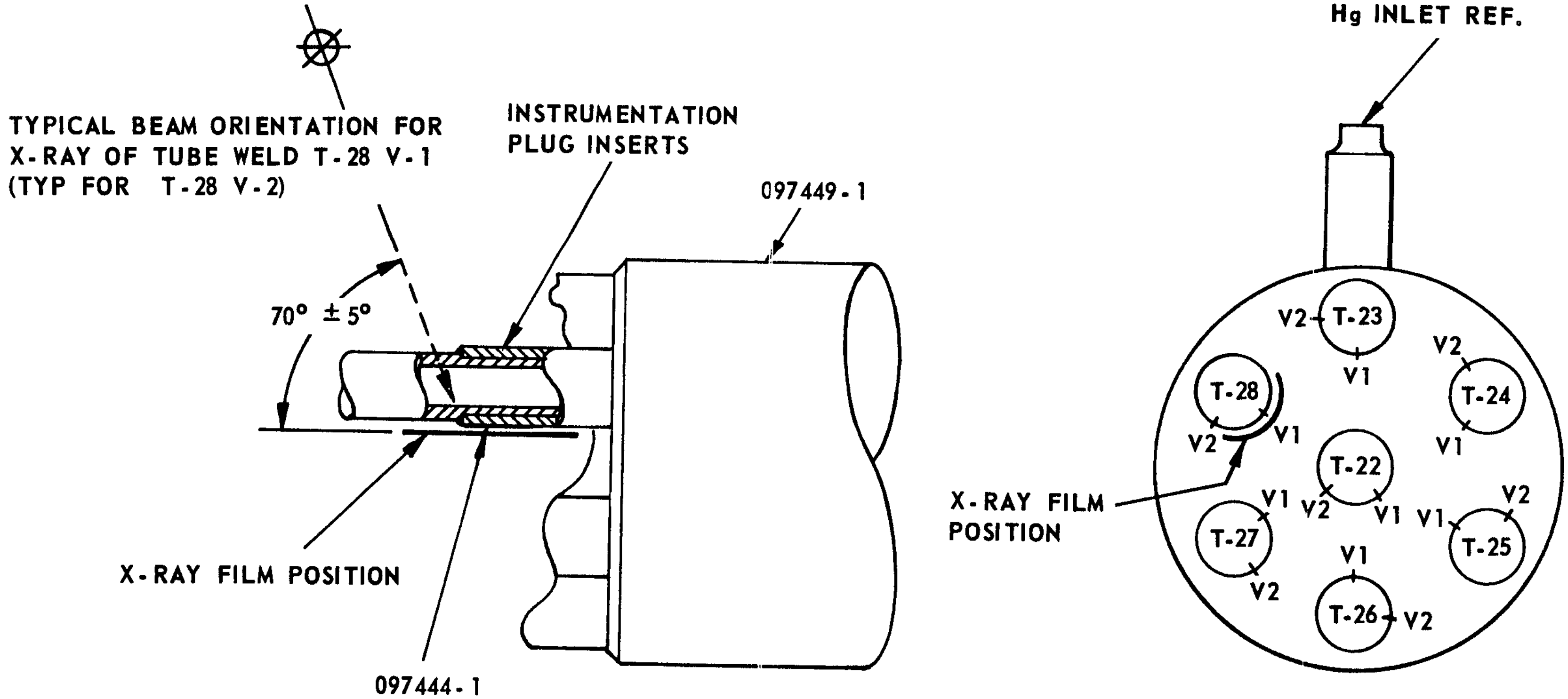
A366-NF-1145

Figure VII-6

A366-NF-1153

NOTES:

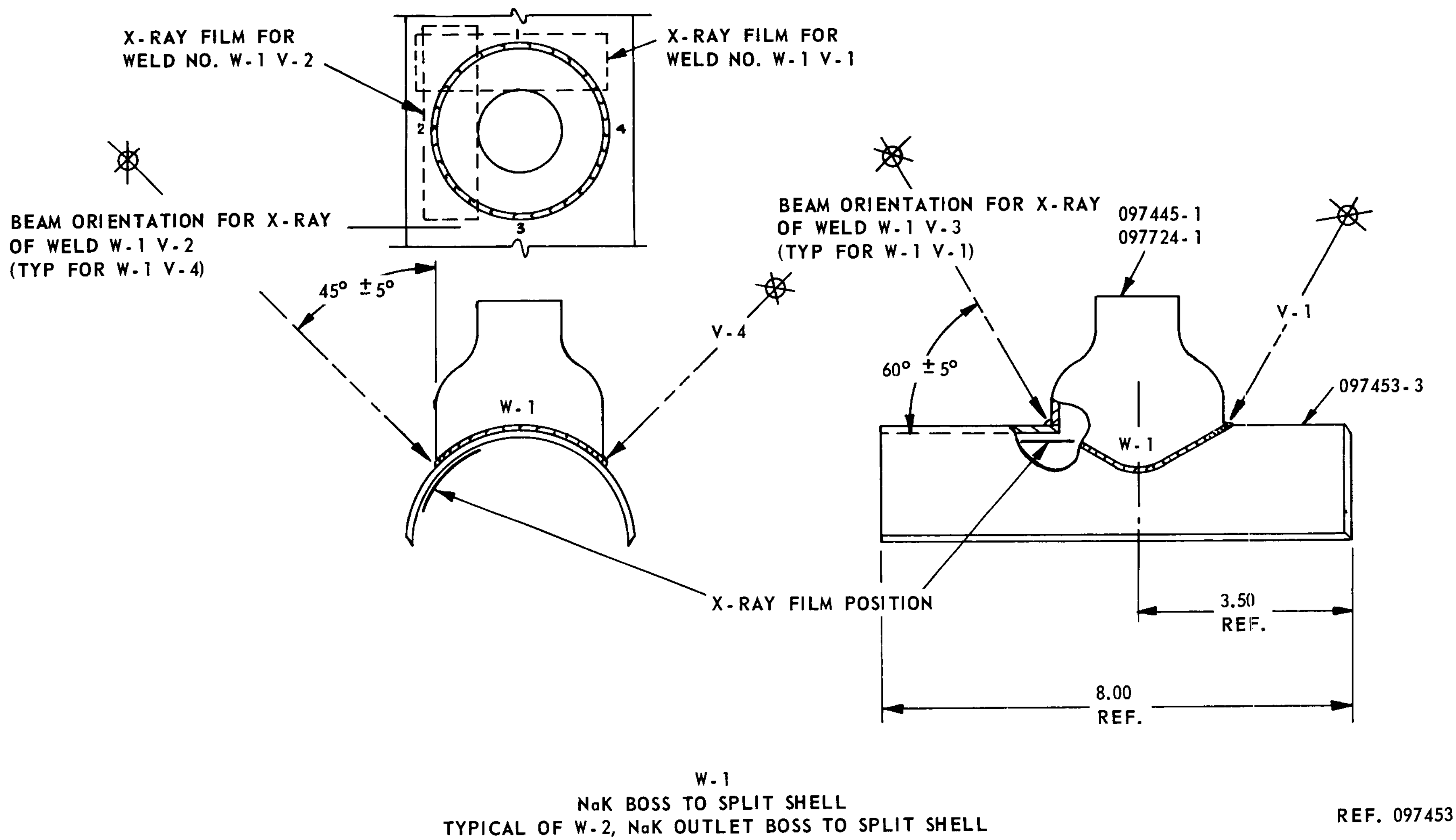
1. IDENTIFICATION OF WELDS TO BE ORIENTED TO Hg INLET STUB AS SHOWN.
2. THIS SET-UP TYP FOR TUBE WELDS T-22 THROUGH T-28.
3. MORE THAN ONE WELD MAY BE X-RAYED WITH A GIVEN EXPOSURE.



T-22 THROUGH T-28
PLUG INSERTS TO HOUSING

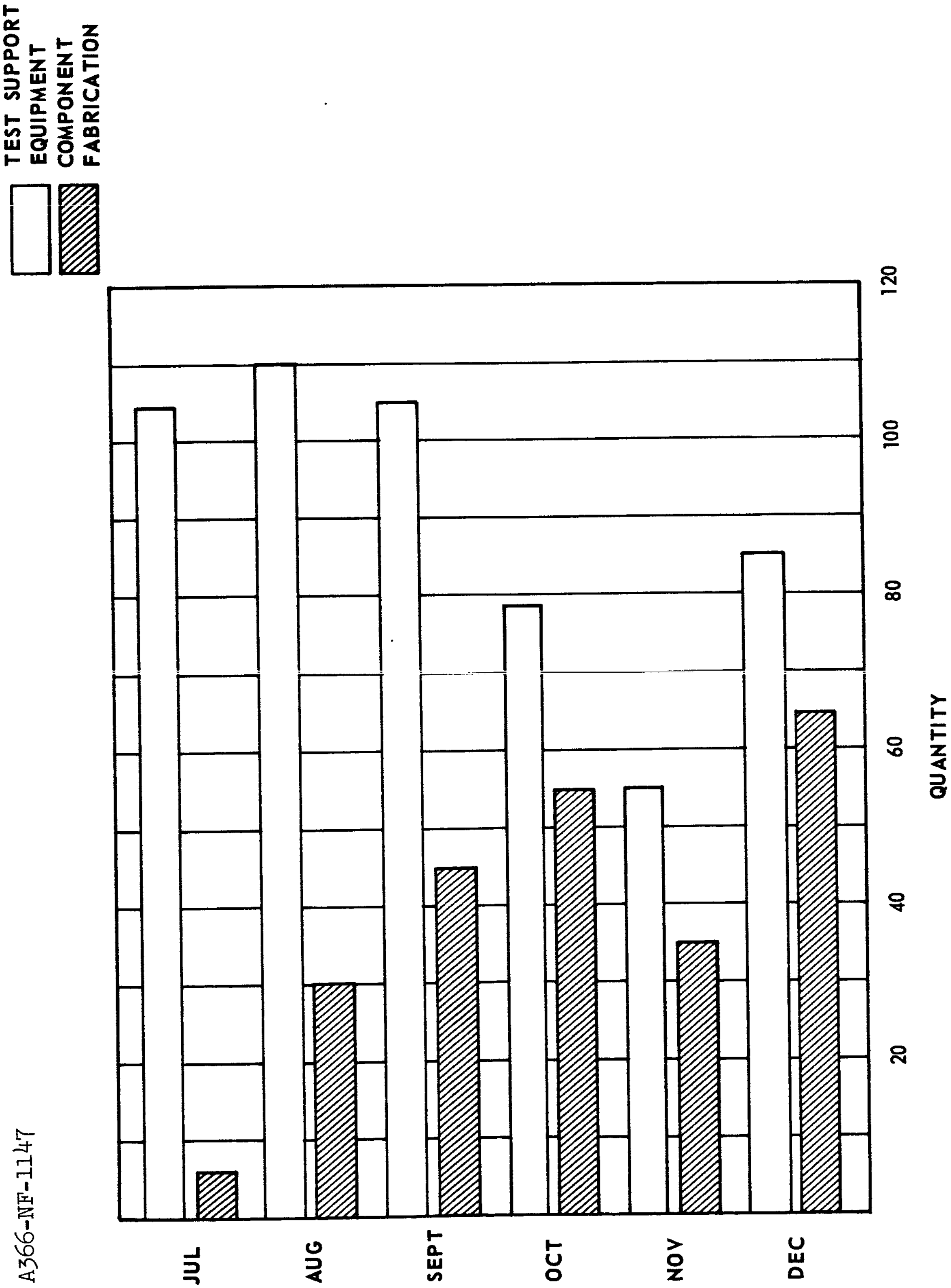
REF. 097444

Radiographic Inspection Requirements for Welds Joining Plug Inserts to Housing



Radiographic Inspection Requirements for
Welds Joining NaK Boss to Split Shell

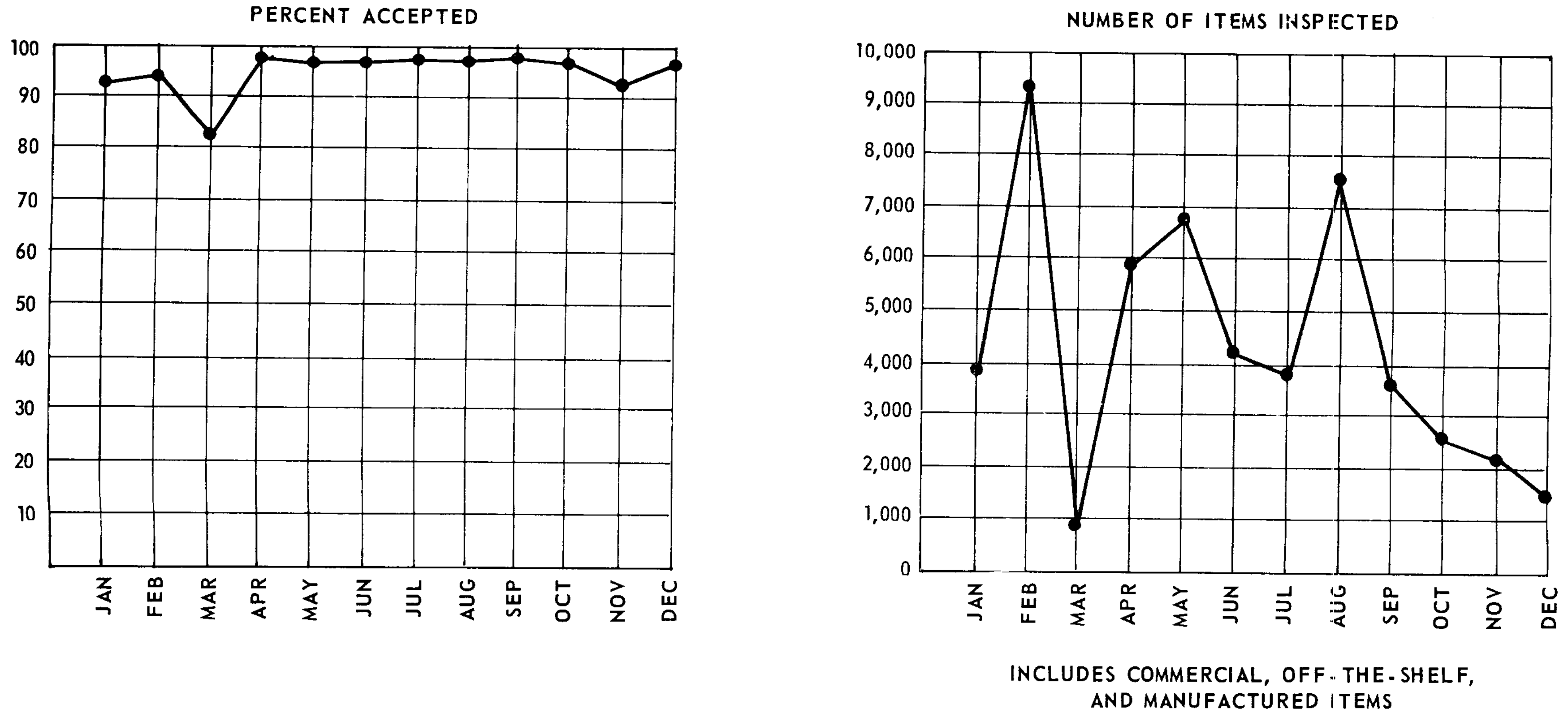
A366-NF-1147



Stores and Purchase Requisitions Reviewed for Integration of Quality Control Requirements

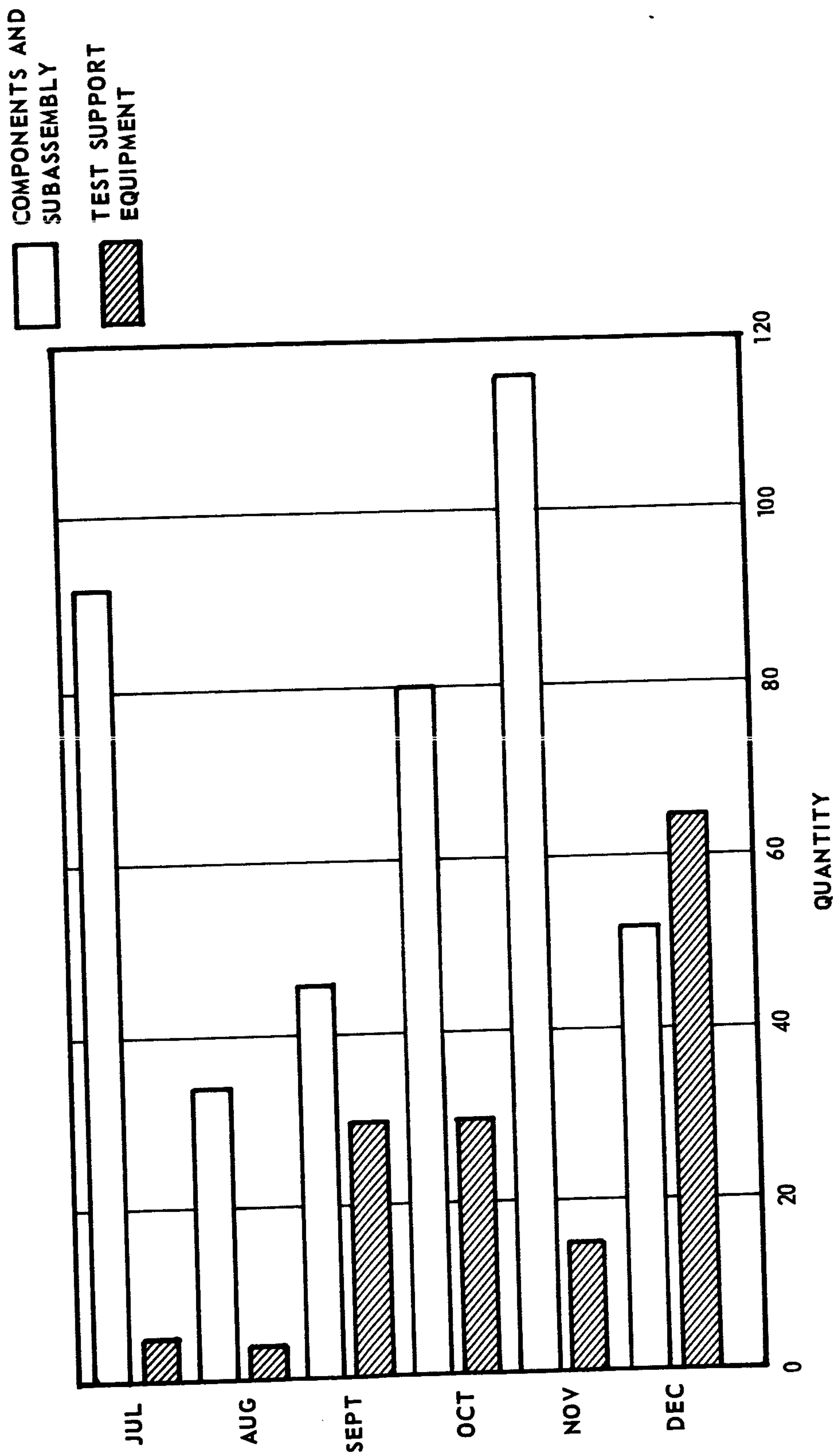
Figure VII-9

A366-NF-1146



Summary of Items Inspected and Receiving Inspection Acceptance

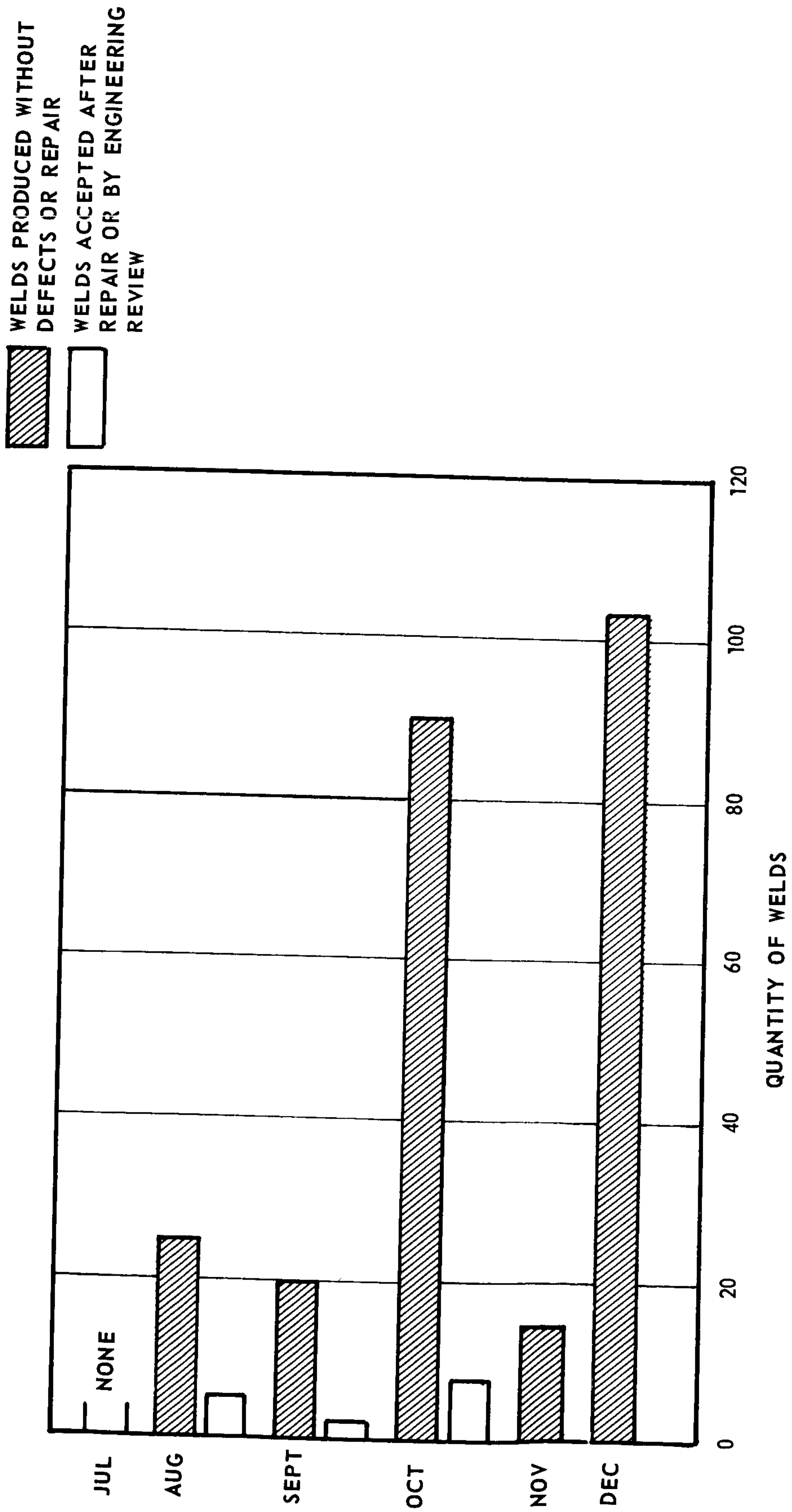
Figure VII-10



A366-NF-1148

Shop Orders Reviewed and Inspection Requirements Incorporated

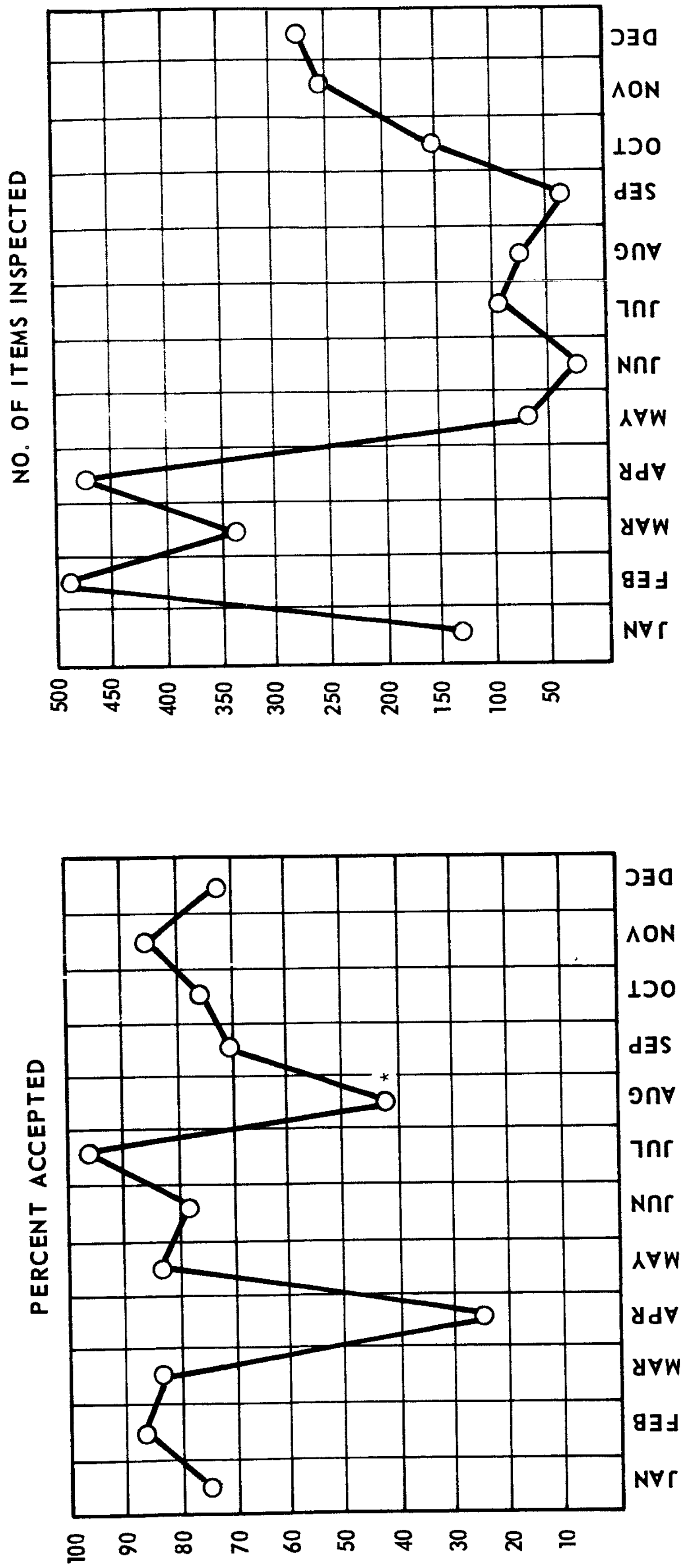
Figure VII-11



Inspection Results of Weld Quality in PCS-1 Phase IV

A366-NF-1142

Figure VII-12



*LOW ACCEPTANCE RATIO DUE TO NON-CONFORMANCES FOUND IN SUPPLIER FURNISHED MATERIALS.

Quality Summary of In-Plant Items Inspected and Accepted

A366-NF-1144

Figure VII-13

REFERENCES

1. Rated Power Loop 2 Review, Aerojet Report 3065, 8 September 1965.

2. J. N. Hodgson, RPL-2 Tube-In-Tube Boiler Test Specifications, Aerojet Technical Memorandum TM 4933:65-7-342, 19 October 1965.

3. J. N. Hodgson, Condenser Test Specification, Aerojet Technical Memorandum TM 4933:65-7-344, 19 October 1965.

4. J. N. Hodgson, PCS-1 Phase IV Step 1 Test Report, Aerojet Technical Memorandum TM 4952:65-8-366, 12 January 1966.

5. A. H. Kreeger, Preliminary Report - Boiler Performance Map, PCS-1, Phase IV, Step 1 (RPL-2) Tests on P/N 097444-7, S/N A-2, Tube-In-Tube Boiler, Aerojet Technical Memorandum TM 4932:66-386.

6. H. Derow, Evaluation of Tube-In-Tube Boiler Fabrication Samples, Aerojet Technical Memorandum TM 4923:66-387, 15 February 1966.

7. R. W. Marshall, PCS-1/SL-1 Phase II Design, A Final Report, Aerojet Technical Memorandum TM 4942:66-372, 6 January 1966.

8. H. B. Ellis, C. A. Lang, PCS-1/SL-1 Phase I and PCS-1/SL-1 Tube-In-Tube Boiler: The Operations Department Final Report, Aerojet Technical Memorandum TM 4943:65-8-370, 11 January 1966.

9. C. S. Mah, PCS-1/SL-1, Phase I Tests, A Final Report, Aerojet Technical Memorandum TM 4942:65-8-263, 25 October 1965.

10. C. S. Mah, Tube-In-Tube Boiler Testing in PCS-1/SL-1, A Final Report on Its Effect on the System, Aerojet Technical Memorandum TM 4942:66-382, 3 February 1966.

11. J. N. Hodgson, Test Plan, Turbine-Alternator Assembly, P/N 096800-1, S/N A-2, Aerojet Technical Memorandum TM 4933:65-7-347, 11 November 1965.

12. J. N. Hodgson, Electrical Controls Test Plan, Aerojet Technical Memorandum TM 4933:65-7-350, 11 November 1965.

13. J. R. Pope, Test Plan for Mercury Pump-Motor Assemblies, P/N 098100-1 and P/N 093347-5 in PCS-1 Phase IV, Aerojet Technical Memorandum TM 4932:66-7-352, 3 January 1966.

14. C. P. Colker, NaK Pump-Motor Assembly Test Plan - Steps II and III Testing in PCS-1, Phase IV, Aerojet Technical Memorandum TM 4932:65-7-361, 7 January 1966.

REFERENCES (cont.)

15. J. N. Hodgson, Mercury Flow Control Valve, P/N 097330-5, S/N A-3 Test Plan, Aerojet Technical Memorandum TM 4933:65-7-346, 11 November 1965.

16. J. N. Hodgson, Test Plan - Step 2 Testing in PCS-1, Phase IV, Aerojet Technical Memorandum TM 4933:65-7-353, 17 November 1965.

17. M. G. Cherry, Test Request for Turbine-Alternator Assembly (P/N 096800-1 S/N A-2) in PCS-1 Phase IV Development Tests, Aerojet Technical Memorandum TM 4933:65-7-348, 16 December 1965.

18. N. E. Waldschmidt, Test Request for PCS-1, Phase IV, Step 2, Electrical Controls Tests, Aerojet Technical Memorandum TM 4936:65-7-349, 20 January 1966.

19. C. P. Colker, NaK Pump-Motor Assembly Test Request for Steps 2 and 3 Testing in PCS-1, Phase IV, Aerojet Technical Memorandum TM 4932:65-7-360, 21 January 1966.

20. I. L. Marburger, J. N. Hodgson, Test Specification RPL-2 Mercury Flow Control Valve, Aerojet Technical Memorandum TM 4933:65-7-345, 27 October 1965.

21. J. N. Hodgson, PCS-1, Phase IV, Step 2, Test Specification, Aerojet Technical Memorandum TM 4952:65-7-371, 21 January 1966.

22. J. N. Hodgson, SNAP-8 Component Operating Envelopes, Aerojet Technical Memorandum TM 4933:65-1-318, 19 October 1965.

23. Interim Report on the First Integrated System Test (FIST) Plan, Aerojet Report 3083, 1 October 1965.

24. L. P. Lopez, SNAP-8 PCS-G Configuration Study, Aerojet Technical Memorandum TM 4962:65-2-368, 29 December 1965.

25. M. G. Cherry, A Performance Potential Study for the SNAP-8 Turbine, Aerojet Technical Memorandum TM 4932:66-391.

26. W. M. Waters, Failure Analysis of the SNAP-8 Turbine-Alternator Assembly 3/2, S/N A-3, Aerojet Technical Memorandum TM 4932:65-5-332, 14 October 1965.

27. SNAP-8 Electrical Generating System Development Program Progress Report for January - June 1965, Aerojet Report 3053, August 1965.

28. SNAP-8 Electrical Generating System Development Program, Aerojet Report L0740-05-7, July 1965.

REFERENCES (cont.)

29. SNAP-8 Electrical Generating System Development Program, Aerojet Report L0740-05-8, August 1965.

30. SNAP-8 Electrical Generating System Development Program, Aerojet Report L0740-05-11, November 1965.

31. SNAP-8 Electrical Generating System Development Program, Aerojet Report 0390-04-16, June 1964.

32. SNAP-8 Electrical Generating System Development Program, Aerojet Report 0390-04-17, October 1964.

33. SNAP-8 Electrical Generating System Development Program, Aerojet Report 0390-04-18, January 1965.

34. SNAP-8 Electrical Generating System Development Program, Aerojet Report 0390-04-15, March 1964.

35. R. S. Carey, B. E. Farwell, G. Thur, Effects of Oil Contamination on Heat Transfer Performance of Forced-Convection Mercury Boilers, Paper presented at AIAA First Rankine Cycle Space Power Systems Specialists Conference, October 1965.

36. A. H. Kreeger, J. N. Hodgson, A. J. Sellers, Development of the SNAP-8 Boiler, Paper presented at AIAA First Rankine Cycle Space Power Systems Specialists Conference, October 1965.

37. A. J. Sellers, M. K. Wong, Experimental Investigation of Forced Convestion Once-Through Mercury Boiler Performance Characteristics, Aerojet Technical Memorandum TM 4933:65-8-311, 3 August 1965.

38. Properties of SNAP-8 Fluids, NaK and Mercury, ET-378, Aerojet-General Corp., March 1964.

39. A. J. Sellers, SNAP-8 Tube-In-Tube (TIT) Boiler Design Analysis (Ref. Dwg. L097306), Aerojet Technical Memorandum TM 4803:65-2-223, February 1965.

40. J. N. Hodgson, Condenser Test Specification, Aerojet Technical Memorandum TM 4933:65-7-344, 19 October 1965.

41. A. H. Kreeger, Performance Map of the SNAP-8 -1 Model Condenser, P/N 092500-1, S/N A-2, Aerojet Technical Memorandum TM 4932:66-381, 19 January 1966.

REFERENCES (cont.)

42. L. G. Rico, SNAP-8 Mercury -1 Condenser Design Analysis, Aerojet Technical Memorandum TM 4831:64-1-250, 2 December 1964.

43. I. L. Marburger, Test Report, Mercury Flow Control Valve, P/N 097330-5, S/N A-3, Aerojet Technical Memorandum TM 4932:66-383, 20 January 1966.

44. R. G. Geimer, Analysis of a SNAP-8 EGS Based on Unmodified -1 Component Performance, Aerojet Technical Memorandum TM 4922:65-1-323, 3 September 1965.

45. SNAP-8 Materials Report for July - December 1965, Aerojet Report 3134, March 1966.

46. E. G. Brittain, R. D. Schilling, SL-1 Controls Evaluation and Phase II Proposal, Aerojet Technical Memorandum TM 4936:65-1-313, 16 August 1965.

47. H. E. Rice, D. E. Hartvigsen, SNAP-8 Rated Power Loop No. 2 Event Summary 6/1/64 - 4/1/65, Aerojet Technical Memorandum TM 4922:65-3-308, 30 June 1965.

48. G. G. Takach, SNAP-8 Quality Program Plan, Aerojet Report 2405, 1 October 1965.